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THE PREPARATION OF 90 MM AND 100 MM BORE BEARINGS FOR PERFORMAN--ETC(U)

JUL 78 W E WARD

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THE PREPARATION OF 90 MM AND 100 MM BORE BEARINGS FOR PERFORMANCE EVALUATION IN A SIMULATED SPACE ENVIRONMENT

Nonmetallic Materials Division
Lubricants and Tribology Branch

July 1978

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WRIGHT-PATTERSON AFB, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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Many past and present satellite systems employ despun antenna platforms to provide for data transfer as well as command and control communications. The mechanism which permits this antenna platform to be despun with respect to the rest of the satellite is called "DESPIN MECHANICAL ASSEMBLY" or DMA. The heart of this assembly is the DMA bearing. Because this bearing is required to perform precisely over a long period of time, the preparation of this bearing for its mission is of critical importance. This report describes the techniques

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20. Abstract (Continued)

~~we have~~ used to prepare DMA bearings for laboratory investigations which will lead ultimately to the development of accelerated life tests and prediction techniques. The need for careful inspection of bearings as well as the importance of a good physical characterization of the bearing components is discussed. Additionally, a detailed lubrication procedure is presented.

FOREWORD

This report was prepared in the Air Force Materials Laboratory, Lubricants and Tribology Branch (MBT), Nonmetallic Materials Division, Wright-Patterson Air Force Base, Ohio. The investigation was performed under Project 7343 "Aerospace Lubricants", Task 734303 "Fluid Lubricant Materials and under Project 2421 "Aerospace Fluids, Lubricants and Fluid Containment", Task 242102 "Lubricating Materials and Tribology", Work Unit 24210201 "Accelerated Tests and Life Prediction for Space Bearings/ Lubricants", and covered the period from July 1973 through September 1977.

This report was submitted by the author in January 1978.

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SECTION I

INTRODUCTION

Historically, predictions of long-term bearing performance have been based either on extrapolations of past experience or on the results of testing of components under more severe conditions that would be encountered during actual operation. When applied to space systems such as the despin mechanical assembly (DMA) (Figure 1), neither of these techniques imparts a sufficiently high level of confidence that the mission requirements can be successfully achieved (Reference 1). In the past, this problem has been overcome by simply testing the hardware under simulated operational conditions to the desired life (usually about three years), thus providing a real-time demonstration of capability. Satellite systems currently in development have projected orbital mission lifetimes of 7-10 years. For missions of this duration, the costly and time consuming real-time testing of components is neither practical nor desirable. Techniques which enable accurate prediction of life expectancy and quality of performance over the long-term space mission are needed. Having recognized that this desired predictive capability does not presently exist, the Air Force Materials Laboratory has undertaken a multiphased in-house and contractual (References 2 and 3) program to correct this deficiency. The first phase of this program included a compilation and analysis of both operational and ground test life performance data/experience of despin mechanical assemblies (DMA's) for spacecraft antenna, the principal objective being the identification of real and potential failure mechanisms. During this phase (of about 18 months duration), ten spacecraft systems, both military and commercial, were surveyed and 12 potential bearing and/or lubrication failure mechanisms were identified. Included among these were lubricant degradation, lubricant dewetting, slip-ring and brush wear, improper lubricant transfer, inadequate lubricant quantity, lubricant volatility, incompatibility of the lubricant with other materials present, torque variations, separator and bearing instability, separator wear, lubricant creep, and film thickness. A more detailed explanation and discussion of each of these can be found in Reference 1.

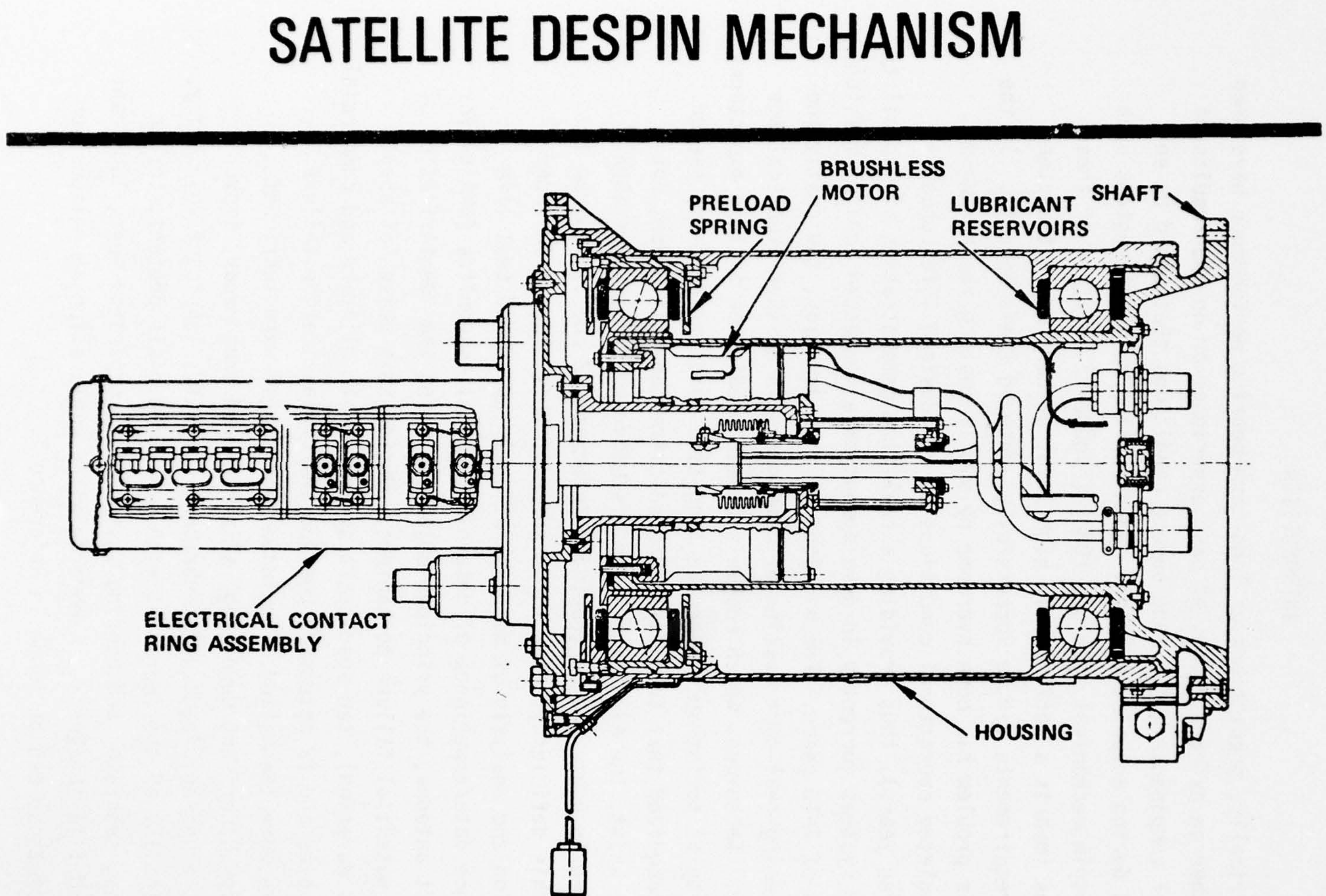


Figure 1. Typical Military Satellite Despin Mechanism

SECTION II
APPROACH

At an early stage, it was recognized that in order to investigate many of the postulated failure modes, it would be necessary to have on hand a number of lubricated space quality bearings. Although the cleaning and lubrication of bearings to flight quality is available commercially, this service is extremely costly and would not have allowed us the flexibility we require. Therefore, it was decided to develop an internal capability to prepare bearings for testing as needed and in the manner desired. Although accelerated testing of despin antenna bearings has previously been undertaken by other groups (References 4 and 5), little useful information could be uncovered concerning the preparation of test specimens. Some data was available through other DOD agencies and NASA, but even this varied considerably from source to source. It was concluded that there is no single acceptable nor industry-wide technique. What follows are the approaches and techniques that are being used to prepare our bearing test specimens for use in the investigation of lubricant degradation, dewetting, and lubricant quantity, and the influence of these lubricant parameters on bearing torque, torque noise, and overall performance. It should be kept in mind that this investigation both requires and challenges our capability to detect subtle, almost imperceptible, changes in both materials and performance over a relatively long period of time. Because of this, extraordinary care must be taken in the preparation of test specimens to ensure success. This preparation includes four phases: inspection, metrology, cleaning, and lubrication, and each of these will be discussed in the following section.

SECTION III

DEVELOPMENT OF CLEANING AND LUBRICATION PROCEDURES

1. TEST SPECIMEN DESCRIPTION

The bearings to be prepared for testing (i.e. processed) are both 90 mm and 100 mm bore angular contact ABEC-7 ball bearings. The metallic components are either 52100 or 440C steel and the separator material is grade LBB cotton phenolic. These bearing sizes and materials are typical of despin bearings and the metal parts usually have a surface finish of about 0.102 μm (3-4 μ in.) on the races and 0.025 μm (1 μ in.) on the balls. Table 1 lists some of the physical characteristics of these bearings.

2. INSPECTION

Recently, a brief, but excellent review (Reference 6) of the subject of bearing manufacturing techniques and procedures appeared in which the author pointed out that some "routine" procedures in the bearing manufacturing plant, ultrasonic cleaning and abrasive tumbling, for example, may ultimately be detrimental to long-life satellite operation. We agree with this postulate and suggest that preparation of a bearing for either ground testing or orbital operation must begin with manufacture. Even if one is sufficiently careful to preclude detrimental handling or processing of the bearing before delivery, it must undergo rigorous inspection, cleaning, and re-lubrication before use. Each of these steps is equally important, and failure to perform any one correctly has the potential to cause system malfunction.

Bearings are usually received assembled. After receipt, the assembled bearing was inspected for gross damage, and after careful disassembly, each of the components was also inspected. At 20x magnification, races appeared smooth, without brinelling, and the grinding marks were visible. Balls were free from scratches or other imperfections. The retainer should be uniform in appearance, and final machining should have left

TABLE 1

PHYSICAL CHARACTERISTICS OF TEST BEARINGS

BORE	90 mm	100 mm
Grade	ABEC-7	ABEC-7
Series	Extra Light	Extra Light
OD	140 mm	150 mm
Width	24 mm	24 mm
Number of Balls	21	21
Ball Size	14.3 mm (.5625 in.)	15.9 mm (.625 in.)
Contact Angle	26 ± 1 degree	26 ± 1 degree
Surface Finish		
Races	0.076 - 0.102 μm (3-4 μ in.)	0.076 - 0.102 μm (3-4 μ in.)
Balls	0.025 μm (1 μ in.)	0.025 μm (1 μ in.)
Retainer	LBB phenolic	LBB phenolic
Retainer Guide	Outer Race or Inner Race	Outer Race

the inner and outer edges of the ball pockets smooth. However, this was not always found. Some of the retainers were found to have "rough" edges on the ball pockets left after final machining (Figure 2). At least one retainer had a straight line running around about 180° of the pocket from the OD to the ID in several pockets. This appeared to be the edge of a sheet of the linen which is impregnated with phenolic resin to form the tube of cotton phenolic laminate. It has yet to be demonstrated that this "edge" or line in the ball pocket will have an impact on performance, but it certainly serves to reinforce the need to know precisely the condition of the separator. Assuming that no imperfections were found, each bearing was then superficially cleaned ultrasonically to remove shipping oil, and the appropriate bearing components were scribed with identifying numbers before characterization.

3. METROLOGY

The type and size of bearings utilized in satellite DMA's are what are considered by most manufacturers to be non-standard bearings. Because of this, and because of the relatively small number required, the commercial sources for obtaining these bearings are few. Although the bearings used in the study are of fine quality and meet the ABEC-7 standard, nevertheless, the first step in our laboratory is to fully characterize the bearing and all its components. This characterization includes measurement of parameters such as surface roughness of balls and races, various race radii, and some of the basic dimensions of the separator. There are several reasons for this: First, although simple in appearance, the analysis of the performance of a bearing/lubricant system is a formidable task. Second, although the metallic components are manufactured to strict tolerances, the design of the separator and selection of lubricant materials have not been optimized. Third, modern diagnostic techniques, such as acoustic signature analysis, require a detailed knowledge of the real physical condition of all the bearing components.

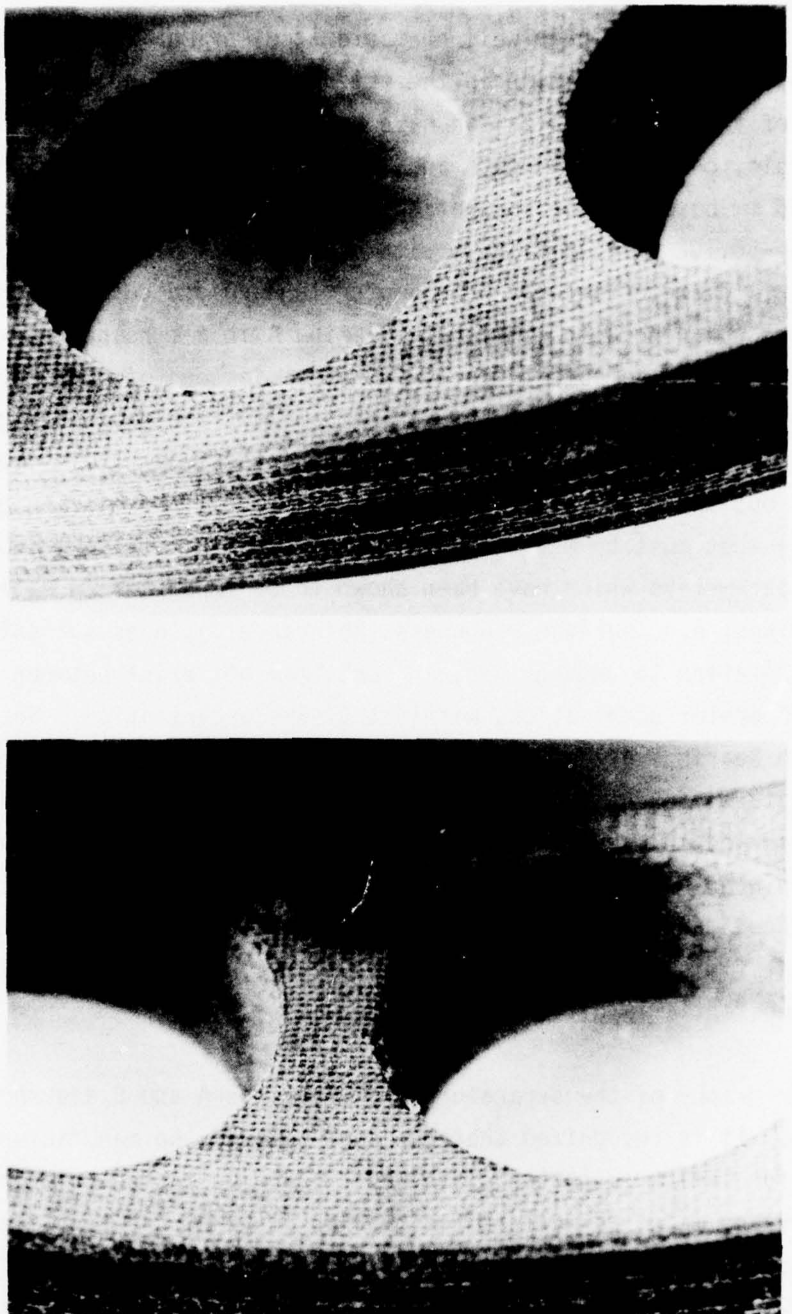


Figure 2. Poorly Finished Retainer Ball Pockets

Our bearings have been well characterized, primarily by an organization with a world-wide reputation in the science of metrology. Some of the results of this characterization have been both surprising and disturbing. For example, compare bearings A and B. Bearing A is a 440C steel, ABEC-7 90 mm bore angular contact ball bearing having a surface finish of 0.076 - 0.102 μm (3-4 μ in.), with a complement of 21 balls of 14.3 mm (.5625 in.) diameter and having an outer land guided cotton phenolic separator. Bearing B is similar to bearing A in all respects except that the metallic components are 52100 steel instead of 440C. Table 2 lists some comparative characterization data for the two bearings as well as several others which have been characterized. It is important to point out that, for most of these measurements, there is no established tolerance that must be met. In addition, repeatability in measurement of some parameters which have been shown to be important in satellite DMA bearings, e.g. surface roughness (Reference 3), does not exist from one organization to another and, in fact, may not exist between two machine/operator combinations within the same organization. So, while these two bearings are of the same quality, ABEC-7, they are also, in fact, quite different in many important aspects. Further, much of the data presented in Table 2 is "arithmetic average" (AA). Care must be exercised when utilizing this type of data. Figure 3 shows polar graphs of the "best" and "worst" ball from each bearing. All four balls have AA surface finishes of approximately 0.01 μm (0.3-0.4 μ in.) and yet they appear substantially different.

Polar graphs of the separators from bearings A and B are shown in Figure 4. It is recognized that the control over the manufacturing process for laminated cotton cloth based phenolic tubing from which retainers are made, as well as the "workability" of the final product, do not approach those of the metallic components. At the same time, however, there is evidence (References 2, 7, and 8) that the stability of the retainer can be a major factor in the overall performance of the bearing. In addition to the geometry of the porous retainer, the capability of this material to absorb and dispense lubricant over the life of the mission, also is of prime importance. Here, again, the lack

TABLE 2

METROLOGY DATA FOR BEARINGS

TABLE 2
METROLOGY DATA FOR BEARINGS

	BEARING A[1] (AF-08)		BEARING B[1] (AF-23)		BEARING C[1] AF-21)		BEARING D[1] (AF-22)		BEARING E[2] (AF-04)	
	μm	μ in.	μm	μ in.	μm	μ in.	μm	μ in.	μm	μ in.
OUTER RACE										
CIRCUMFERENCE										
Roundness - Radial Deviation	1.78	70	0.64	25	0.43	17	0.75	30	0.63	25
Surface Finish (AA)	0.02 - 0.06	0.7 - 2.5	0.01 - 0.03	0.4 - 1.0	0.01 - 0.03	0.4 - 1.0	0.01 - 0.03	0.4 - 1.0	-	-
CROSS RACE										
Deviation of Radius (average)	3.10	122	0.38	15	0.25 - 0.64	10 - 25	0.25	10	-	-
Surface Finish (AA)	0.15	6	0.05 - 0.06	2 - 2.5	0.04 - 0.05	1.7 - 2.0	0.005	0.2	-	-
INNER RACE										
CIRCUMFERENCE										
Roundness - Radial Deviation	1.14	45	0.38	15	0.94	37	1.0	40	1.25	50
Surface Finish (AA)	0.02 - 0.06	0.7 - 2.5	0.005 - 0.03	0.2 - 1.0	0.01 - 0.03	0.4 - 1.0	0.005 - 0.02	0.2 - 0.9	-	-
CROSS RACE										
Deviation of Radius (average)	1.47	58	1.91	75	0.64 - 1.27	25 - 50	3.75	150	-	-
Surface Finish (AA)	0.18	7	0.10 - 0.15	4 - 6	0.05 - 0.10	2 - 4	0.06 - 0.16	2.5 - 6.5	-	-
BALLS										
CIRCUMFERENCE										
Roundness - Radial Deviation	0.03 - 0.05	1 - 2	0.03 - 0.05	1 - 2	0.03 - 0.05	1 - 2	0.03 - 0.05	1 - 2	0.025	1
Surface Finish (AA)	0.01	0.4	0.008-, 0.013	0.3 - 0.6	0.008- 0.02	0.3 - 0.6	0.008- 0.02	0.3 - 0.6	-	-
SEPARATOR										
CIRCUMFERENCE										
Roundness - ID	25.4	1000	40.6	1600	66.1	2600	45.7	1800	-	-
Roundness - OD	25.4	1000	45.7	1800	45.7	1800	40.6	1600	144	5750
POCKETS										
Surface Finish (Average)	1.68	66	1.22	48	1.14	45	1.53	61	-	-
Low	1.22 - 1.60	48 - 63	0.81 - 1.07	32 - 42	0.76 - 1.14	30 - 45	1.1 - 1.3	44 - 52	-	-
High	1.98 - 2.59	78 - 102	1.14 - 1.60	45 - 63	1.09 - 1.60	43 - 63	1.8 - 2.2	72 - 88	-	-

1 Data obtained from Eli Whitney Metrology Laboratory, Bendix Automation and Measurement Division.

2 Data obtained from AFFDL

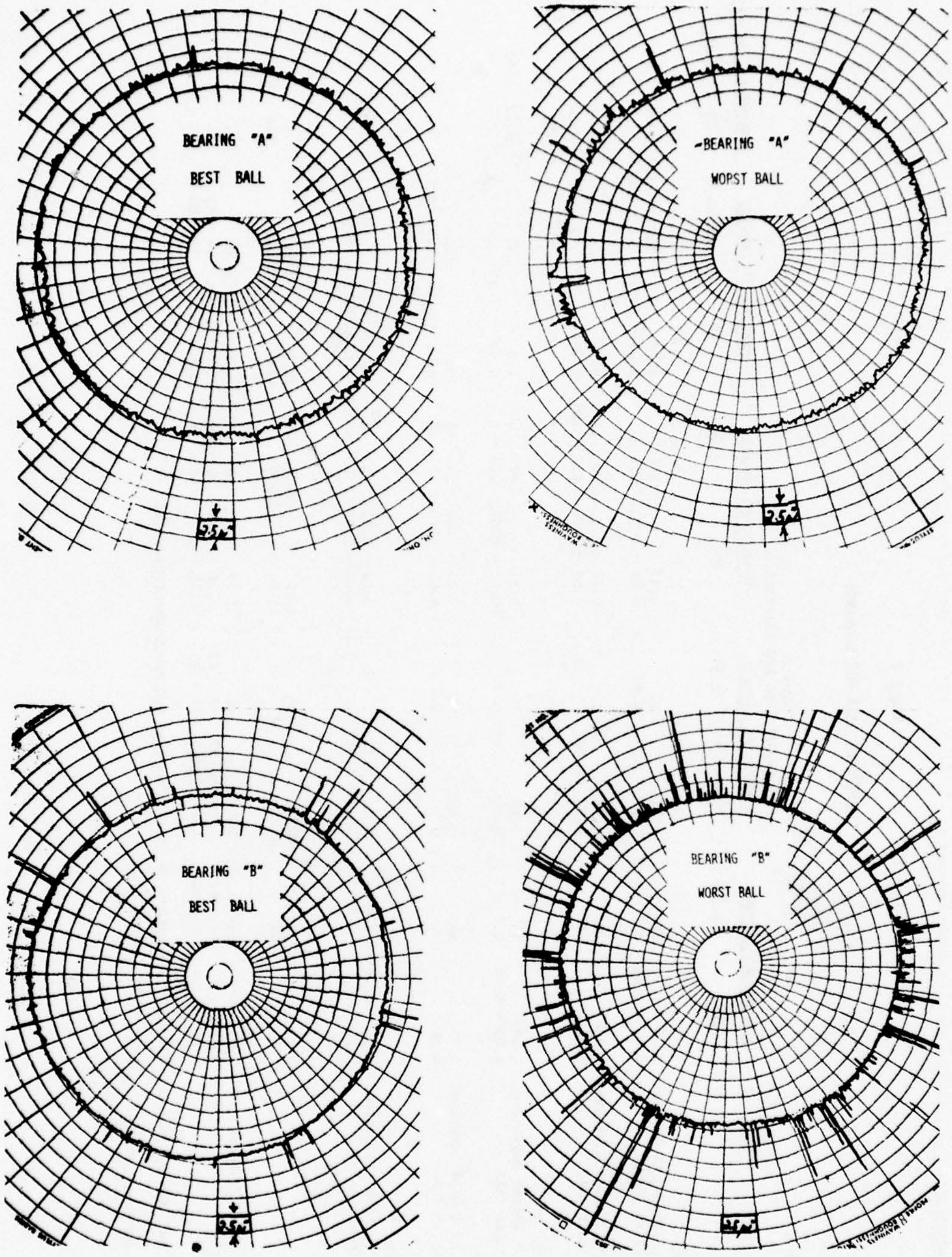


Figure 3. Polar Graphs of Balls from Bearings A and B

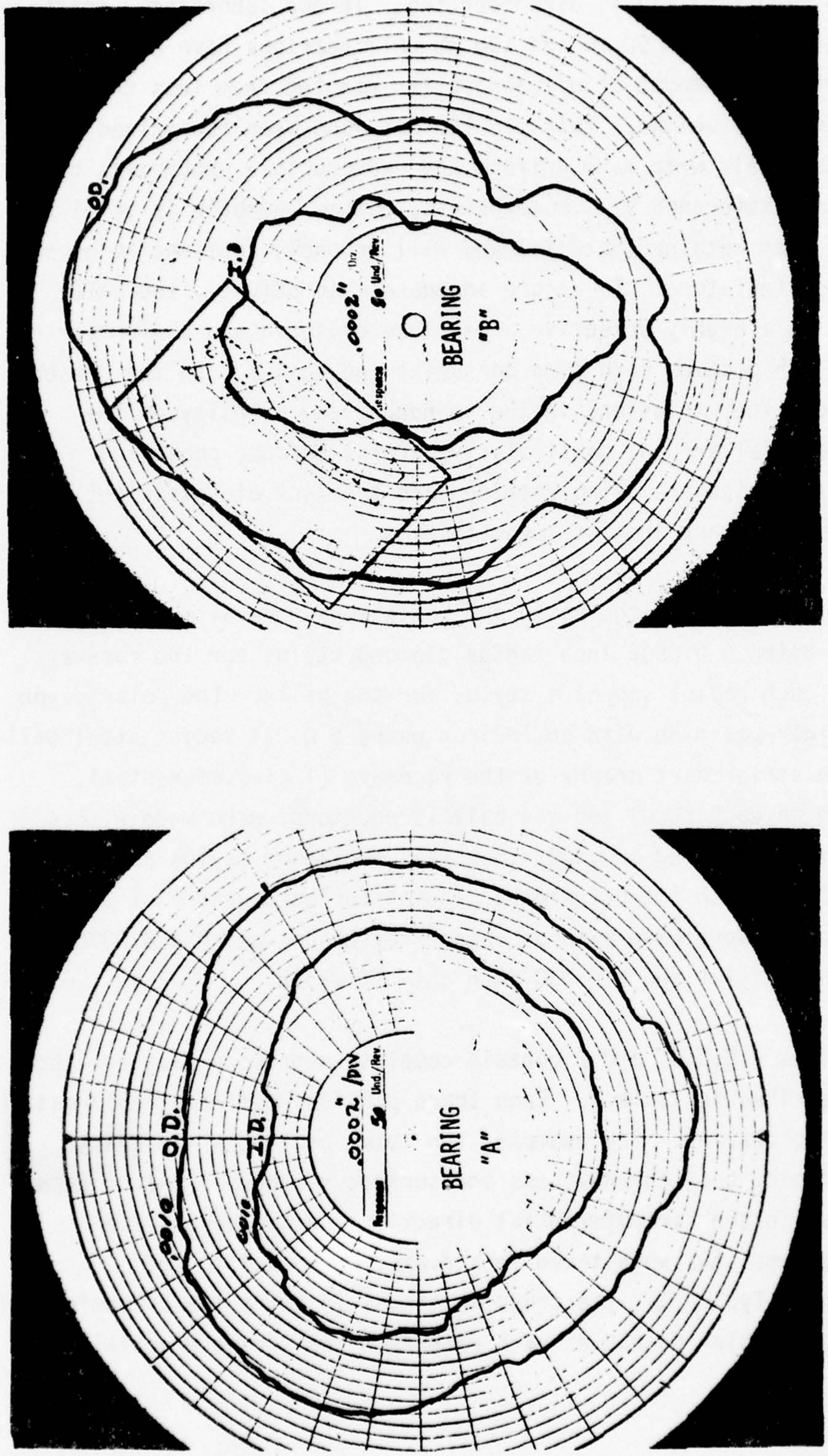


Figure 4. Polar Graphs of the Separators from Bearings A and B

of adequate repeatability is disconcerting. In our laboratory, cotton phenolic retainers from 90 mm and 100 mm ball bearings have been processed with the amount of oil absorption ranging from less than 1% to more than 8% by weight. This problem has long been recognized, and other materials with more uniform and reproducible properties have been proposed (Reference 9). Nonetheless, cotton phenolic is still the most widely used retainer material and will probably continue to be so in the immediate future. To ensure adequate absorptivity, the only alternative is a highly selective acceptance criteria and evaluation procedure which becomes both time consuming and costly. In the present investigation, the variations in the roundness and porosity of the separator material are not particularly harmful because cause and effect relationships are being examined and the lack of sufficient lubricant is a primary area of investigation.

The polar graphs of the races and balls were made with a Rotary Proficorder using a 0.0005 inch radius diamond stylus for the raceways and a 0.046 inch radius sapphire stylus for the balls. The polar graph of the retainer was made with an Indiron using a 0.031 radius steel ball stylus. The strip chart graphs of the raceways (1 circumferential, 1 cross-race on each race) and one ball (2 equators) were made with a Rotary Proficorder using a 0.0005 inch radius diamond stylus and equivalent 0.030 inch cut-off width. The strip chart graphs of the retainer pockets were made with a Linear Proficorder using a 0.0005 inch radius diamond stylus and a 0.030 inch cut-off width.

Appendices A,B,C,D, and E contain complete metrology data for the bearings described in Table 2. Each trace provides different information concerning the bearing. For example, the total profile strip chart recordings depict both the waviness and surface roughness (AA) of each race when run in the circumferential direction and the cross-race surface roughness (AA) when taken in a direction normal to the circumference. Typically, the cross roughness is twice the circumferential roughness. The polar charts of each race show the circumferential

radial deviation from roundness in one case, and the cross-race deviation of the radius in the other case. Similarly, the strip chart graphs for the balls yield the surface finish (AA) while the polar graph depicts the radial deviation from roundness and, in addition, gives another look at the surface quality. Finally, the polar graphs of the retainer depict the considerable radial deviation from roundness while the strip chart graphs give some appreciation of the pocket surface finish (AA).

4. CLEANING

Beginning with the cleaning process, extreme care was exercised in the manner in which the bearing components were handled. For example, only lint proof gloves and solvent cleaned utensils were used to touch the bearing. All glassware was solvent cleaned ultrasonically and oven-dried at temperatures to 100°C before use. All solvents and lubricants were filtered before use, and their purity was checked analytically when possible. Finally, an accurate record of all weighings and visual observations was kept.

It has been found that, throughout the cleaning process, it is advisable to keep the races, balls, and retainer separated. The reason for this is that some processes (ultrasonic cleaning, for example) when performed on an assembled bearing, may cause fretting and degradation of the surface finish (Reference 6), while this same technique, when applied to the unassembled components, should not. Because there are some basic differences in cleaning of metallic and nonmetallic components, each will be discussed separately.

After visual inspection and characterization, the retainer was weighed to the nearest 0.1 mg. To do this, a balance was chosen that also has the capacity to weigh the entire assembled bearing. The retainer was then rinsed using a pressure rinser equipped with a 0.45 micron final filter. The choice of solvent for this purpose, as well as cleaning in general, is not consistent among the organizations involved in bearing processing. For cleaning of cotton phenolic, solvents were chosen which best accomplished each objective

in the cleaning sequence. In the first step, for example, the desired result was the removal of surface preservative oil (if any exists). For this purpose, hexane was chosen although freon, heptane or several other solvents could be used. The next step was to ultrasonically clean the retainer for about 15 minutes to remove any subsurface oil left from shipping. Freon was chosen because it appears to be a better solvent for a wider variety of base oils. The retainer was then baked at 65±5°C (150±10°F) for 24 hours. Cotton phenolic softens at about 107-121°C (225-250°F), so the bake-out temperature was carefully controlled. After cooling, the retainer was once again cleaned ultrasonically for about 15 minutes. This time ethanol was used to remove any polar impurities, such as uncured phenol which may have remained. After a second vacuum bake-out, the retainer was placed in a soxhlet extractor (Figure 5) and continuously cleaned for at least 48 hours using filtered hexane or heptane. This is a deeper cleaning technique and the solvent chosen was one that, if not completely removed by vacuum baking, would be least detrimental to the fluid to be impregnated. Since we are using hydrocarbon based lubricants, a hydrocarbon solvent was chosen. After another 24 hour bake-out, the retainer was placed in a crystallizing dish containing filtered heptane or hexane. The dish was placed in a vacuum desiccator, and the retainer was impregnated with solvent under vacuum. A well trapped mechanical pump was used to create the vacuum. This was followed by vacuum bake-out and weighing. The solvent impregnation was repeated for a total of three cycles. The retainer was then ready for either immediate lubrication or for storage in a warm vacuum oven. Figure 6 depicts the changes in weight of a typical DMA bearing retainer throughout an extended cleaning process. Figure 7 demonstrates the propensity of a vacuum dried retainer to abstract moisture from the air, and suggests the need for rapid weighing (preferably in a dry box).

The cleaning of the metallic components was somewhat simpler because they are not porous. Once again, the first three steps were pressure rinsing, ultrasonic cleaning in freon and ethanol, followed by vacuum baking for about one hour. The 440C parts (not the 52100 parts) were

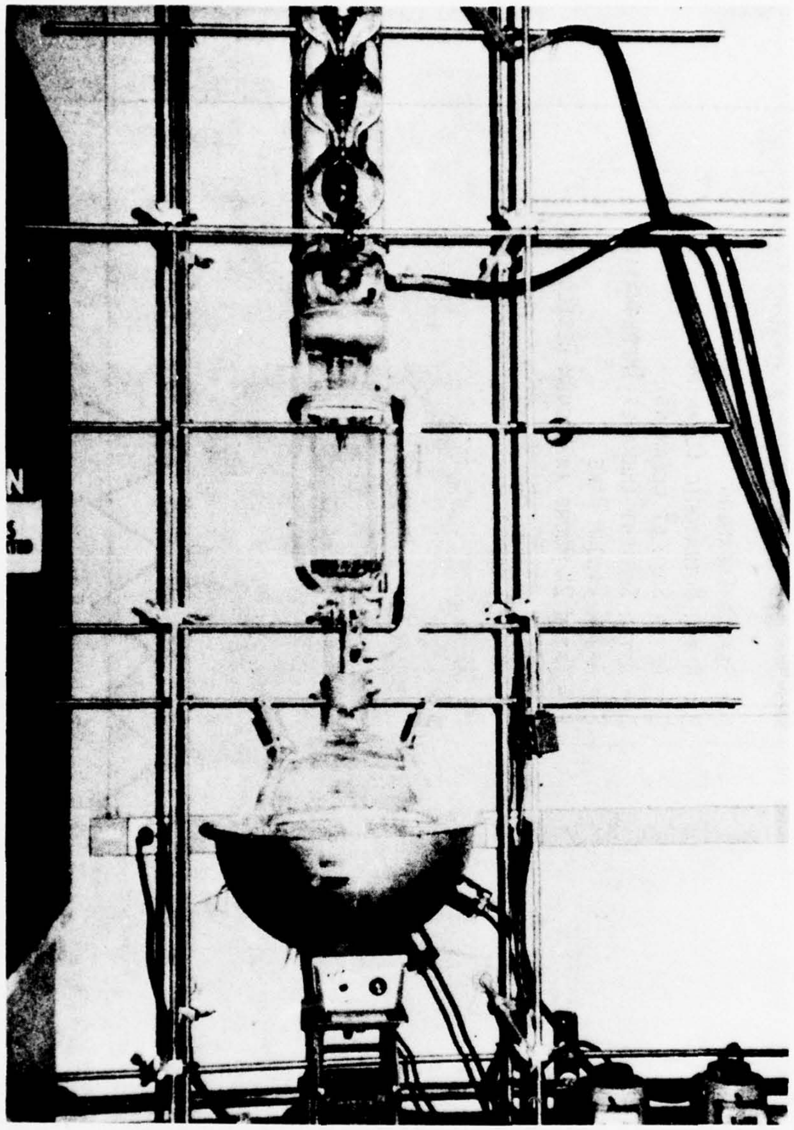


Figure 5. Soxhlet Cleaning Apparatus

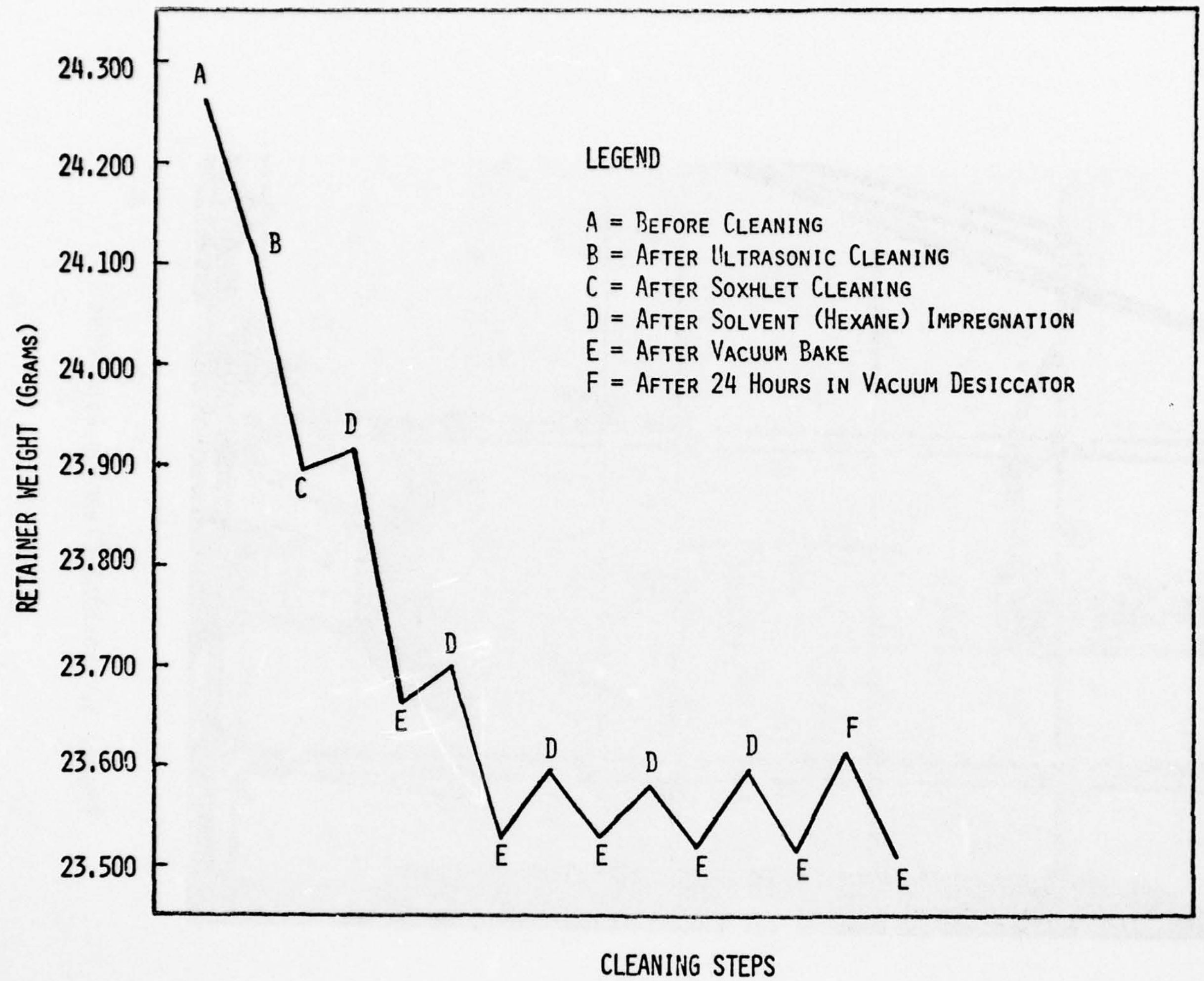


Figure 6. Changes in Retainer Weight During Cleaning

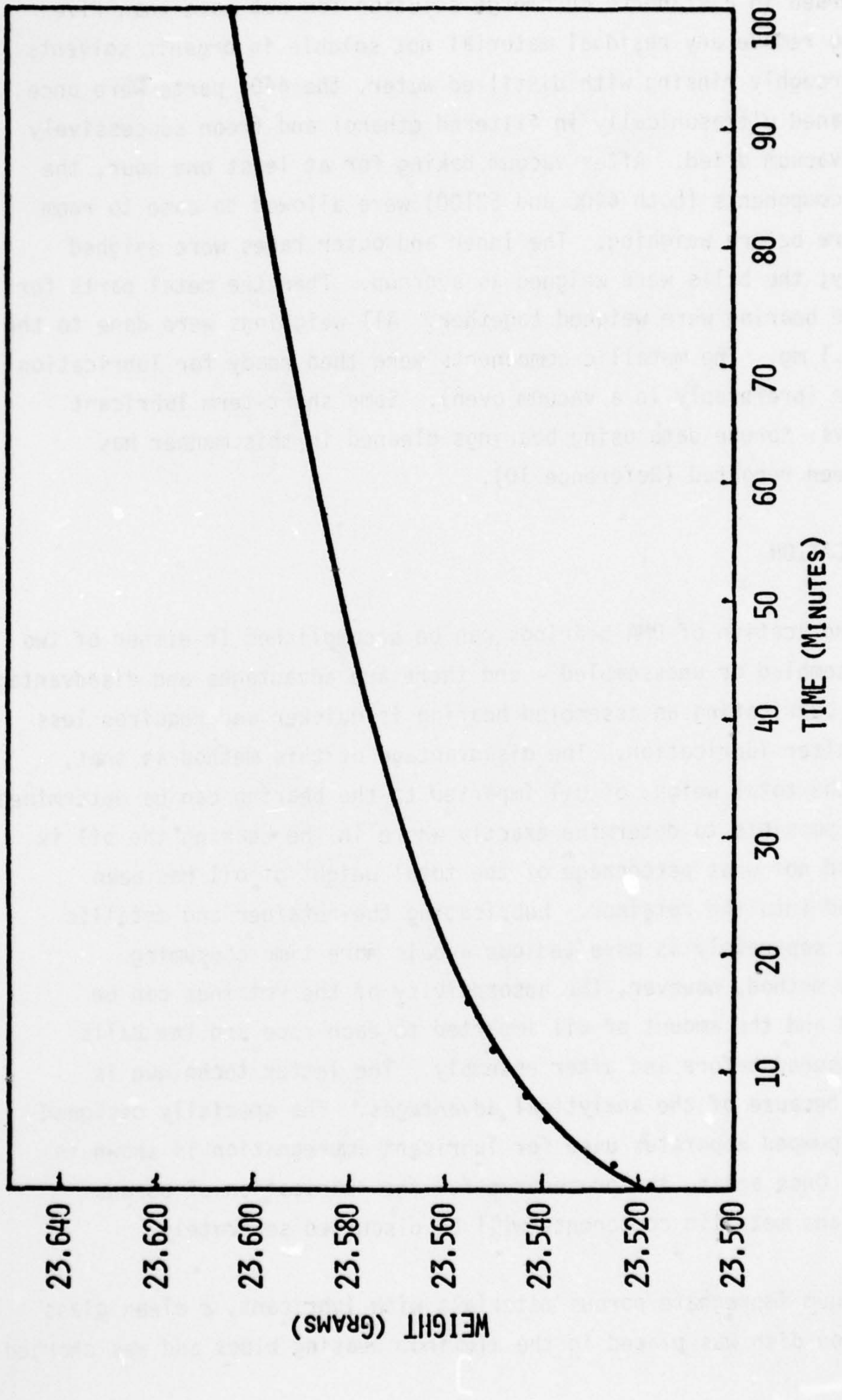


Figure 7. Moisture Absorption of a Vacuum Dried Retainer

then immersed in a standard chromerge solution for not more than five minutes to remove any residual material not soluble in organic solvents. After thoroughly rinsing with distilled water, the 440C parts were once again cleaned ultrasonically in filtered ethanol and freon successively and were vacuum dried. After vacuum baking for at least one hour, the metallic components (both 440C and 52100) were allowed to come to room temperature before weighing. The inner and outer races were weighed separately; the balls were weighed as a group. Then the metal parts for the entire bearing were weighed together. All weighings were done to the nearest 0.1 mg. The metallic components were then ready for lubrication or storage (preferably in a vacuum oven). Some short-term lubricant quantity vs. torque data using bearings cleaned in this manner has already been reported (Reference 10).

5. LUBRICATION

The lubrication of DMA bearings can be accomplished in either of two ways - assembled or unassembled - and there are advantages and disadvantages to both. Lubricating an assembled bearing is quicker and requires less handling after lubrication. The disadvantage of this method is that, although the total weight of oil imparted to the bearing can be determined, it is not possible to determine exactly where in the bearing the oil is to be found nor what percentage of the total weight of oil has been impregnated into the retainer. Lubricating the retainer and metallic components separately is more tedious and is more time consuming. Using this method, however, the absorptivity of the retainer can be determined and the amount of oil imparted to each race and the balls can be measured before and after assembly. The latter technique is preferred because of the analytical advantages. The specially designed diffusion pumped apparatus used for lubricant impregnation is shown in Figure 8. Once again, the procedures for the lubrication of porous materials and metallic components will be discussed separately.

To vacuum impregnate porous materials with lubricant, a clean glass impregnation dish was placed in the aluminum heating block and was charged

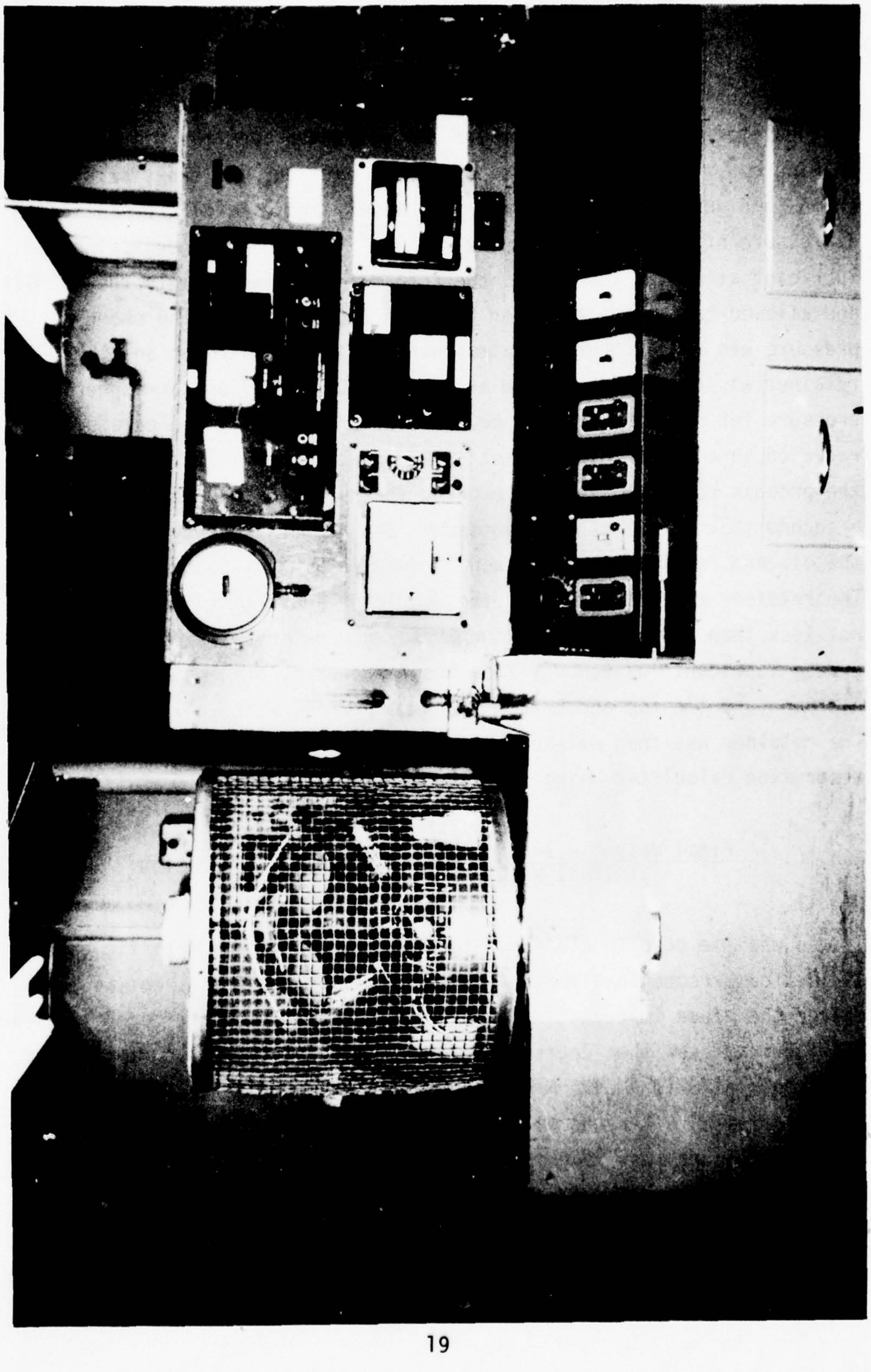


Figure 8. Lubricant Impregnation Apparatus

with approximately 500 ml of lubricant, previously filtered through a 1.2 micron filter. A 15 ml sample of lubricant was removed from the dish for analysis both before and after impregnation. The retainer was weighed to the nearest 0.1 mg and was suspended over the oil as shown in Figure 9. The bell jar was positioned over the impregnation dish shown in Figure 9 and the chamber was slowly and carefully evacuated to a pressure of 6×10^{-3} newton/meter^2 (5×10^{-5} torr). After degassing the lubricant at 65±5°C (149±9°F), the retainer was lowered into the hot oil and allowed to remain there for 24 hours under vacuum. The chamber pressure was then brought to atmospheric with dry nitrogen and the retainer was permitted to soak at about 65°C (149°F) and atmospheric pressure for not less than 24 hours. The chamber was then carefully recycled to a vacuum of at least 6×10^{-3} newton/meter^2 (5×10^{-5} torr) and the process repeated without removing the retainer from the oil. After a second soak at atmospheric pressure, the heaters were turned off, and the oil and retainer were allowed to come to ambient room temperature. The retainer was raised out of the lubricant and allowed to drain for not less than four hours, and then removed from the wire holders. The excess lubricant was removed from the retainer by blowing with dry nitrogen and the top and bottom faces were wiped with a lint free cloth. The retainer was then weighed to the nearest 0.1 mg and the percent absorption calculated using Equation 1.

$$\frac{\text{Final Weight - Initial Weight}}{\text{Initial Weight}} \times 100 = \%\ \text{absorption} \qquad (1)$$

As was the case in cleaning, the lubrication of the metallic parts is less cumbersome than that of the retainer. The first step was to charge the clean impregnation dish with about 500 ml of filtered lubricant. The lubricant was then degassed at about 65°C (149°F) while maintaining the vacuum of 6×10^{-3} newton/meter^2 (5×10^{-5} torr). The heaters were turned off and, after the oil reached ambient room temperature, the chamber pressure was brought to atmospheric with dry nitrogen. Next, the races and the balls were weighed and carefully placed into the oil.

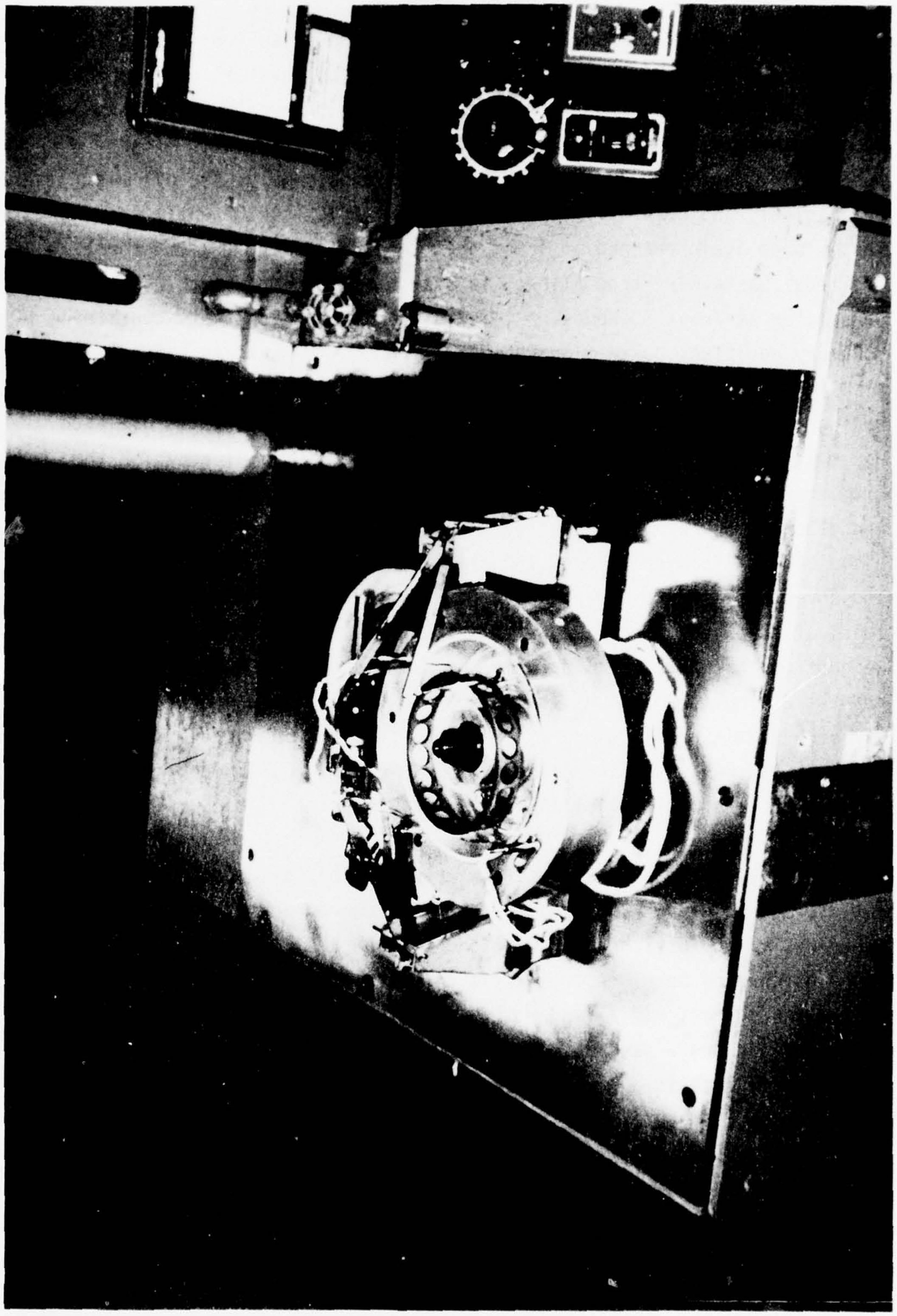


Figure 9. Retainer Suspended Over Glass Impregnation Dish

The oil was sampled for analysis both before and after lubrication in order to evaluate the magnitude of changes in the physical and chemical properties of the lubricant during the lubrication process. In this way, preferential loss of some additives has been detected. After positioning the bell jar over the impregnation assembly, the oil was again slowly and carefully degassed at about 65°C (149°F) until the vacuum once again reached at least 6×10^{-3} newton/meter^2 (5×10^{-5} torr). The metal parts were then allowed to soak at this temperature under vacuum for at least 80 hours. It is felt that for lubricants containing boundary additives, oxidation inhibitors, etc., 80 hours is sufficient time to allow these additives to adequately condition the interacting ball and race surfaces. After this soak time had elapsed, the oil bath was again allowed to come to ambient room temperature, after which the chamber pressure was brought to atmospheric. The races were removed and allowed to drain on lint free cloths, covered by a crystallizing dish. The balls were removed and placed into a clean, tared beaker and covered. After draining about four hours, the top and bottom faces of the races were wiped with a lint free cloth and each race was weighed to the nearest 0.1 mg. The balls were also weighed to the nearest 0.1 mg. The amount of lubricant on the races was determined directly from the before and after weighings. The lubricant imparted to the balls was determined after assembly of the bearing by reweighing the beaker (and residual oil).

A nitrogen flushed desiccator (with clean, dry desiccant) was used for storage of either the retainer or metallic components while the other was being lubricated. In this case, the article was placed in a clean, covered petri or crystallizing dish which, in turn, was placed in the desiccator. If a longer term storage is anticipated, it may be best to store the disassembled components in a vacuum oven until ready for use. If this is done, the parts should be reweighed before use and visual inspection confirm a lubricant film on the metallic parts. This precaution is necessary because reports (Reference 11) that assembled bearings, after about 12 months storage, showed evidence of further absorption of surface oil from metallic components by the retainer. Because of this, bearings are tested as soon as possible after lubrication, and not stored for extended periods.

SECTION IV

RESULTS

1. WEIGHT ANALYSIS

Tables 3 and 4 contain the weight histories of two typical DMA bearings from inspection through lubrication. Several points about the data contained in these two tables should be emphasized. First, as described previously, the races and the balls were weighed individually and then collectively for each bearing. For both bearings, the total of the individual weights for the races and balls agree within 0.02 - 0.03% of the collective weight for each step in the cleaning and lubricating process. Second, because lubrication did not follow cleaning immediately in most cases, the weighings were repeated before the lubrication process began. Comparing the "complete bearing" weight after cleaning to the "complete bearing" weight before lubrication, it would appear that there was a weight gain of from 0.02 - 0.04 g. These differences may be real, or could be due to recalibration of balances and weights, differences in humidity, etc. Third, the percent absorption of the retainer was determined by the difference in retainer weight "before" and "after" lubrication and was found to be 8.15% and 1.31% for the bearings in Tables 3 and 4, respectively. Because the "assembled" weight of both bearings after lubrication is consistently about 0.7 g less than the "complete bearing" weight after lubrication, the determination of the oil on the metallic components was more difficult. The method chosen to determine this amount was to subtract the fully lubricated retainer weight from the final assembled bearing weight, the remainder being the final assembled weight of the metallic components. The weight of "ALL METAL COMPONENTS" (Tables 3 & 4) before lubrication was subtracted from this number, giving the amount of oil imparted to the metal parts. Using this method, 0.92 g and 1.30 g for the bearings in Tables 3 and 4, respectively, was found to remain on the metal surfaces after final assembly. From this point of view, what this means is that for the bearing in Table 3, 78.6% of the total lubricant charge is represented by the retainer, while for the bearing in Table 4, 74.4% of the total lubricant charge is contained on the metal surfaces.

TABLE 3

WEIGHT HISTORY OF A DMA BEARING - HIGH PERCENT ABSORPTION RETAINER

	Weight, g	Weight, g	Difference, %
AS RECEIVED			
ASSEMBLED		**1206.700**	
Outer Race	**533.796**		
Inner Race	**325.611**		
19 Balls	**305.235**		
Retainer	**42.268**		
COMPLETE BEARING		**1206.910**	**0.017**
AFTER CLEANING			
ALL METAL COMPONENTS		**1164.440**	
Outer Race	**533.795**		
Inner Race	**325.604**		
19 Balls	**305.231**		
TOTAL		**1164.630**	**0.016**
Retainer	**41.383**		
COMPLETE BEARING		**1206.013**	
BEFORE LUBRICATION			
ALL METAL COMPONENTS		**1164.458**	
Outer Race	**533.801**		
Inner Race	**325.613**		
19 Balls	**305.244**		
TOTAL		**1164.658**	**0.017**
Retainer	**41.377**		
COMPLETE BEARING		**1206.035**	
AFTER LUBRICATION			
ALL METAL COMPONENTS		**1165.829**	
Outer Race	**534.399**		
Inner Race	**325.739**		
19 Balls	**305.934**		
TOTAL		**1166.072**	**0.021**
Retainer	**44.748**		
COMPLETE BEARING		**1210.820**	
AFTER ASSEMBLY		**1210.126**	

TABLE 4

WEIGHT HISTORY OF A DMA BEARING - LOW PERCENTAGE ABSORPTION RETAINER

	Weight, g	Weight, g	Difference %
AS RECEIVED			
ASSEMBLED		1167.958	
Outer Race	488.866		
Inner Race	397.920		
21 Balls	246.503		
Retainer	35.008		
COMPLETE BEARING		1168.297	0.029
AFTER CLEANING			
ALL METAL COMPONENTS		1132.966	
Outer Race	488.853		
Inner Race	397.898		
21 Balls	246.507		
TOTAL		1133.258	0.026
Retainer	34.017		
COMPLETE BEARING		1167.275	
BEFORE LUBRICATION			
ALL METAL COMPONENTS		1132.964	
Outer Race	488.858		
Inner Race	397.893		
21 Balls	246.507		
TOTAL		1133.258	0.026
Retainer	34.078		
COMPLETE BEARING		1167.336	
AFTER LUBRICATION			
ALL METAL COMPONENTS		--------	
Outer Race	489.047		
Inner Race	398.294		
21 Balls	247.606		
TOTAL		1134.947	-----
Retainer	34.525		
COMPLETE BEARING		1169.472	
AFTER ASSEMBLY		1168.790	

The difference in the amount of oil on the metal parts of the two bearings could be due to the difference in both number and size of balls as well as whether the inner or outer race is relieved. The important question is that, in light of the differences between the final lubricated condition of the two bearings, which is the better lubricated? The crux of the answer rests with the ability of the retainer to feed oil to the metal parts. If neither retainer feeds oil, then the bearing from Table 4, although it received far less oil overall, may, in fact, have the longer life expectancy because of where in the bearing the oil is located. It is this type of fundamental question that, hopefully, the laboratory research program will answer.

2. PRELIMINARY BEARING TEST DATA

A small amount of some very preliminary performance data has been obtained on a 90 mm bore bearing cleaned and lubricated by the procedures outlined in this report. This bearing is S/N AF-08, for which the metrology data (Table 2, Bearing A and Appendix A) and lubrication data (Table 4) has already been presented. The lubricant in this test bearing is a commercially available mineral oil based fluid formulated with five percent of a concentrate of lead naphthenate and 1.5 percent of a p,p' dioctyldiphenylamine antioxidant. The bearing test chamber is a modified version of that described in Reference 12. The primary objective of this bearing test was to evaluate the effect of variations in speed and load on torque, with torque ripple and motor current also being monitored. The data presented in Figures 10 and 11 were obtained experimentally by varying the speed of the bearing at a series of constant loads. In general, torque increased with speed in both Figures 10 and 11 although the relationship does not appear to be linear at some speeds. Also, the somewhat anomalous behavior of the torque vs speed curve at 267 N in Figure 11 is suspected to be due to a mechanical problem associated with the "FERROFLUIDIC" feedthrough in the bearing tester drive system. This is currently being evaluated and the results will be presented in a future report devoted to the test rig redesign.

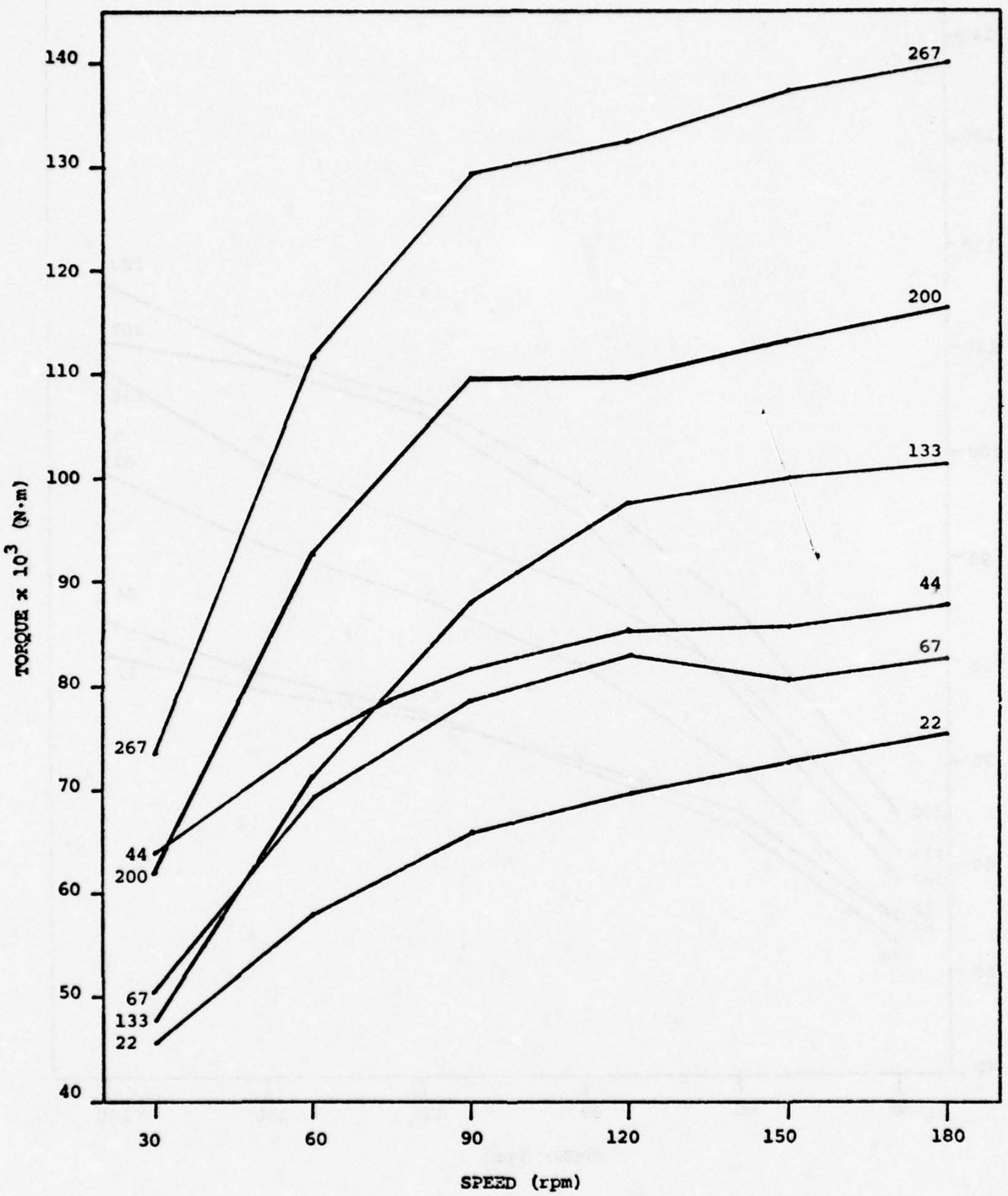


Figure 10. Torque vs. Speed at Various Loads for Bearing AF-08
21-29 September 1977

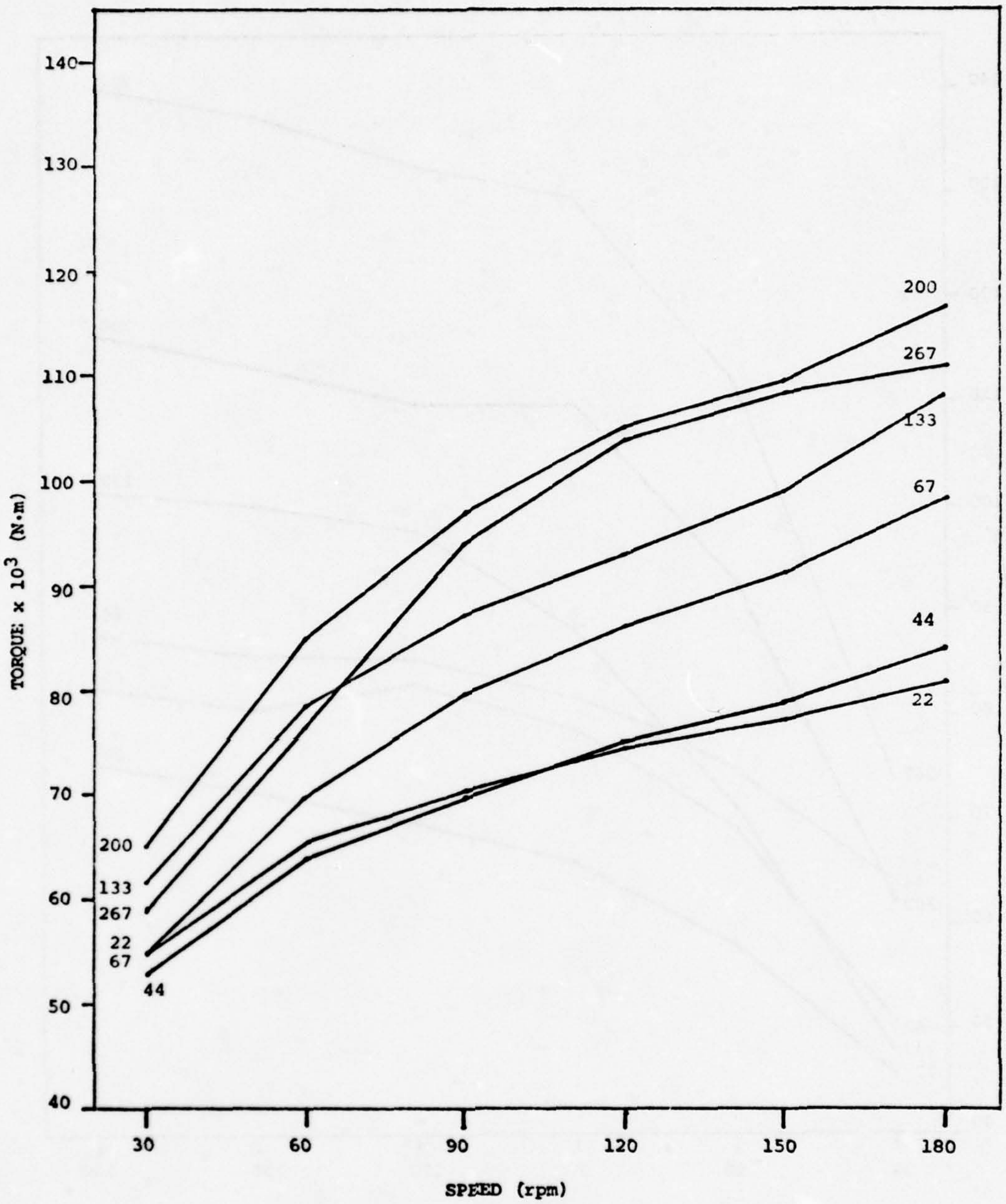


Figure 11. Torque vs. Speed at Various Loads for Bearing AF-08, 7-10 November 1977

Figures 12 and 13 depict the variation of torque with load and were plotted from the same test data as Figures 10 and 11. This is preliminary data and in view of the mechanical problems which have come to light, no overall judgement regarding bearing performance can be made at this time. In addition to the acquisition of some preliminary data, a secondary objective of these tests was to evaluate the capabilities of the test fixture, and in particular, the modifications in the areas of sensitivity, reproducibility, etc. A preliminary evaluation suggests that while the modifications made to the torque sensing system have been beneficial, some additional modification to the drive system as well as the torque sensing system are required before a sufficiently high level of confidence in the torque data can be realized.

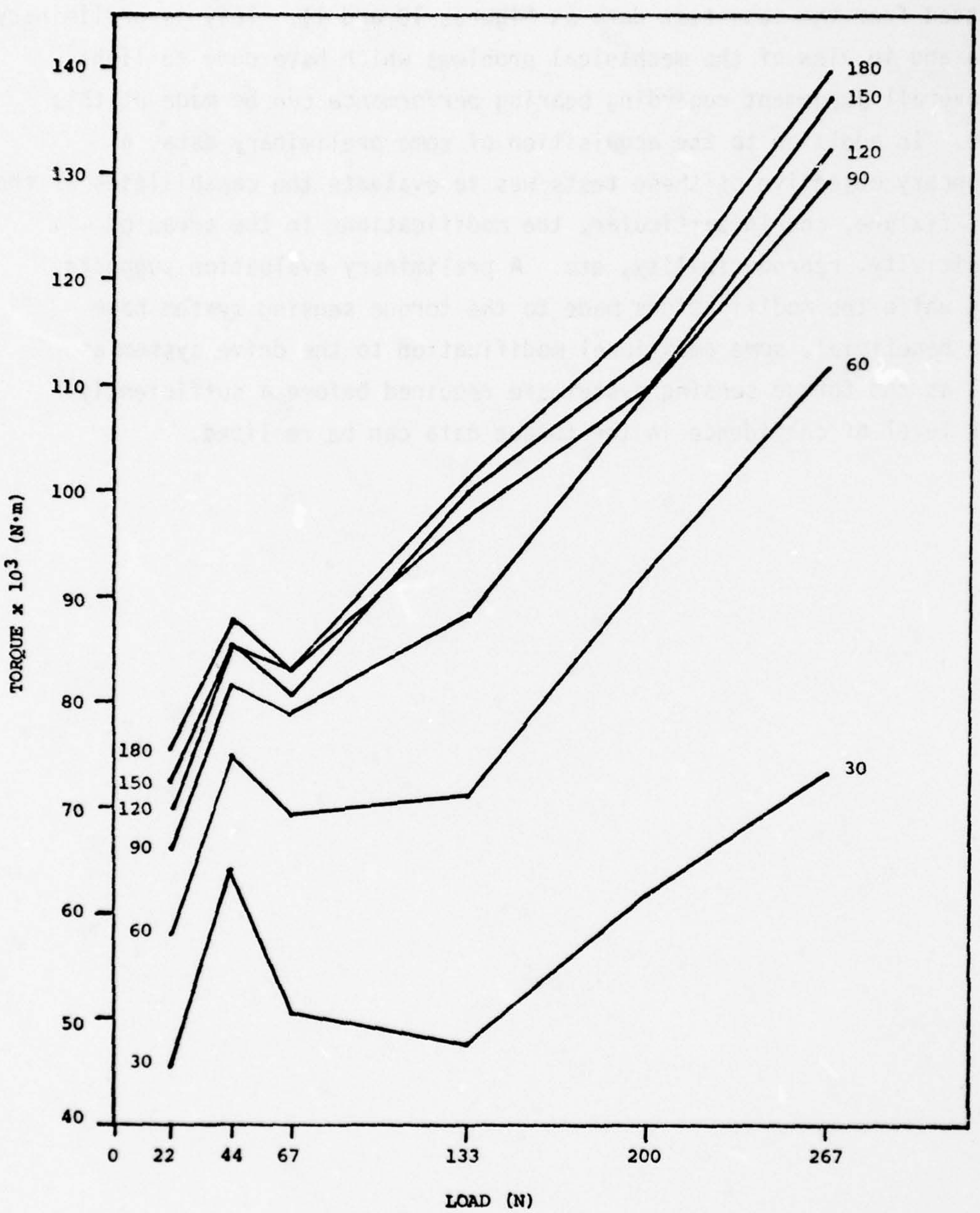


Figure 12. Torque vs. Load at Various Speeds for Bearing AF-08, 21-29 September 1977

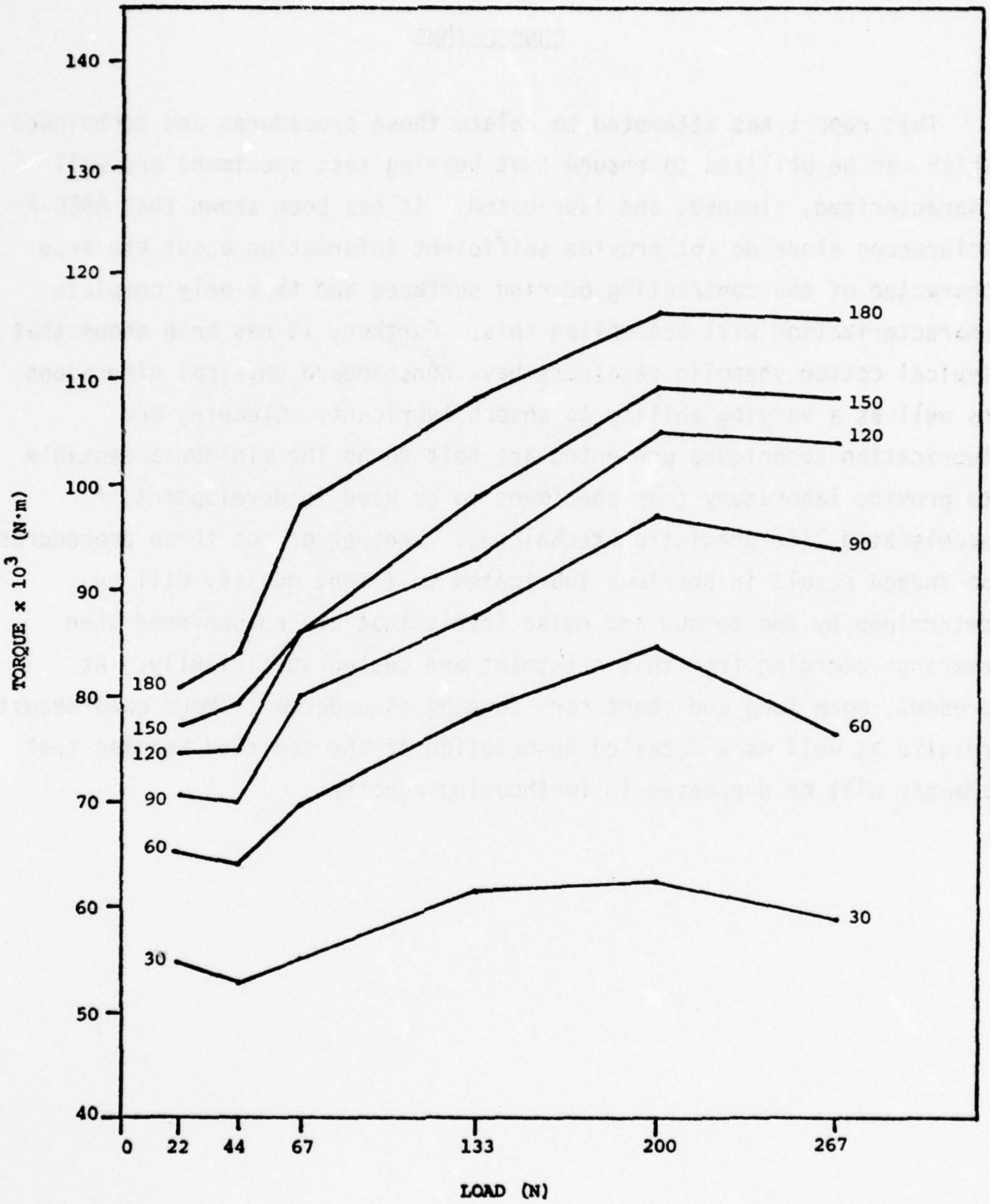


Figure 13. Torque vs. Load at Various Speeds for Bearing AF-08, 7-10 November 1977

SECTION V

CONCLUSIONS

This report has attempted to relate those procedures and techniques which can be utilized to ensure that bearing test specimens are well characterized, cleaned, and lubricated. It has been shown that ABEC-7 tolerances alone do not provide sufficient information about the true character of the contracting bearing surfaces and that only complete characterization will accomplish this. Further, it has been shown that typical cotton phenolic retainers have nonstandard physical dimensions as well as a varying ability to absorb lubricant. Cleaning and lubrication techniques presented are felt to be the minimum acceptable to provide laboratory test specimens to be used in development of accelerated life prediction techniques. Whether or not these procedures do indeed result in bearings lubricated to flight quality will be determined by the torque and noise levels that are encountered when bearings emerging from this treatment are tested sufficiently. At present, both long and short-term testing is underway. More comprehensive results as well as a detailed description of the modified bearing test chamber will be presented in forthcoming reports.

APPENDICES

APPENDIX A - BEARING A

The description and metrology data for Bearing A is presented herewith:

Description:

AFML ID #	:	AF-08
ABEC Grade	:	7
Surface Finish	:	3-4 μin. (nominal)
Bore	:	90 mm
O.D.	:	140 mm
Width	:	24 mm
Contact Angle	:	26 ± 1 degree
Cage Guide	:	Inner Race
No. of Balls	:	21
Ball Diameter	:	14.3 mm (.5625 in.)
Ball/Race Material	:	440C steel
Retainer ID #	:	AF-08
Retainer Material	:	LBB Cotton Phenolic
Retainer Porosity	:	1.31%

Metrology:

This data was obtained through the Eli Whitney Metrology Laboratory, Bendix Automation and Measurement Division, Dayton, Ohio. For the sake of brevity, the complete set of polar graphs illustrating the radial deviation of roundness of all the balls is not presented. Those graphs of balls which are presented are representative of the entire complement and/or illustrate a surface defect of note. For example, in Figure A-7, Ball 1 is representative of a good ball; Ball 2 shows the typical type of roundness deviation; Ball 14 has a characteristic pit, flat or scratch; Ball 6 has high spots in addition to a pit, flat or scratch.

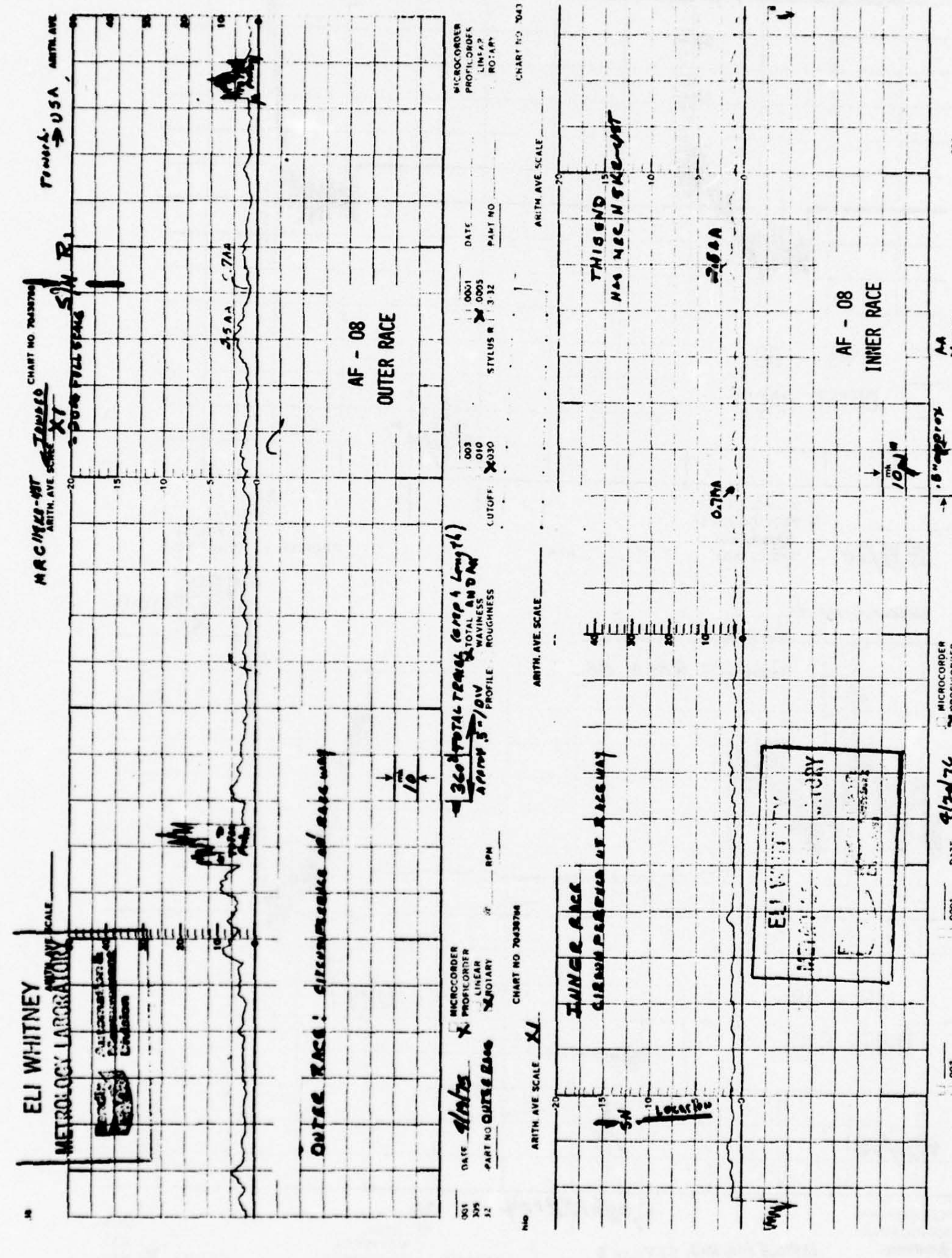


Figure A-1. Circumferential Roughness - Outer Race (Top) and Inner Race (Bottom)

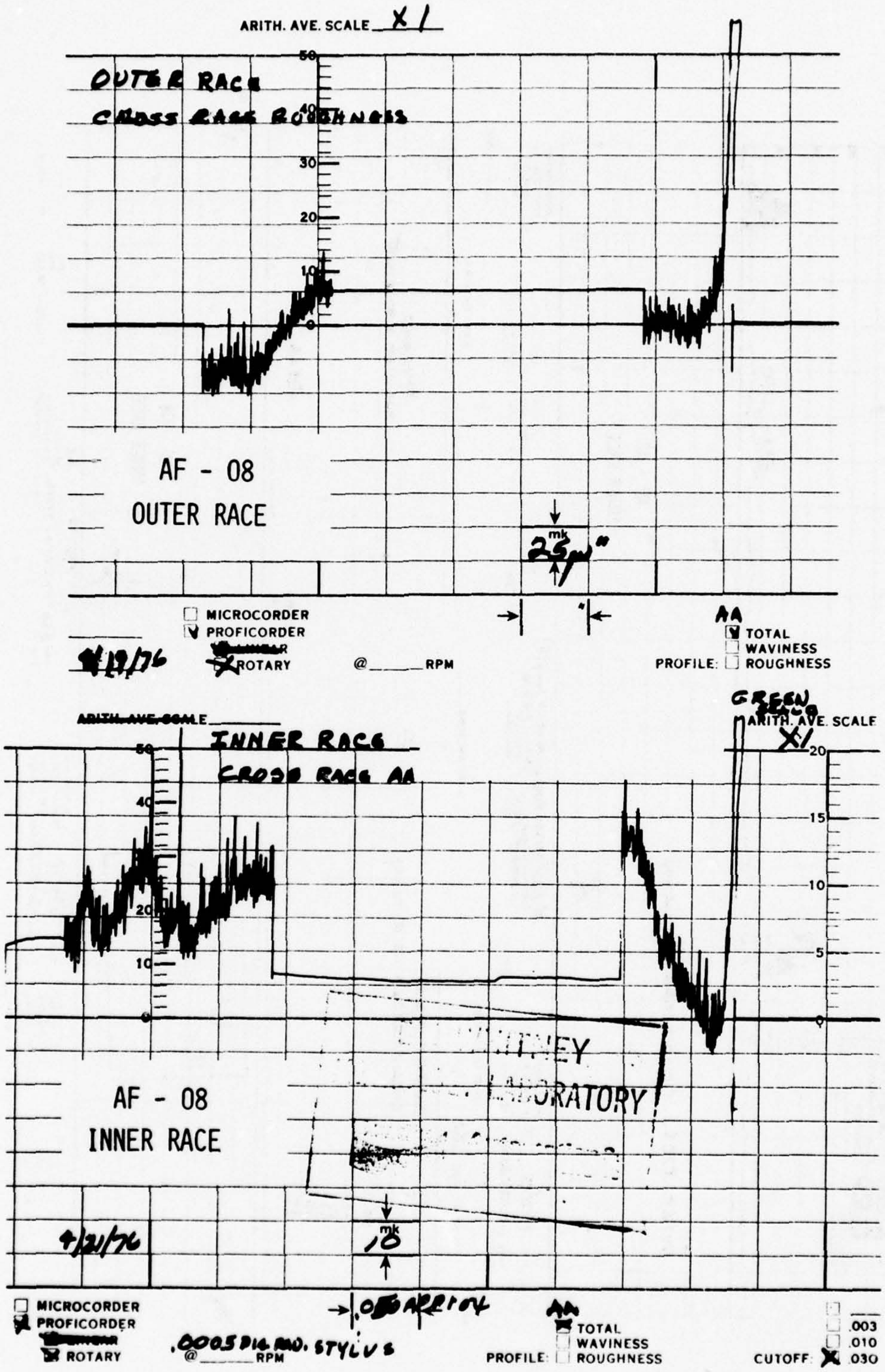


Figure A-2. Cross Race Roughess - Outer Race (Top) and Inner Race (Bottom)

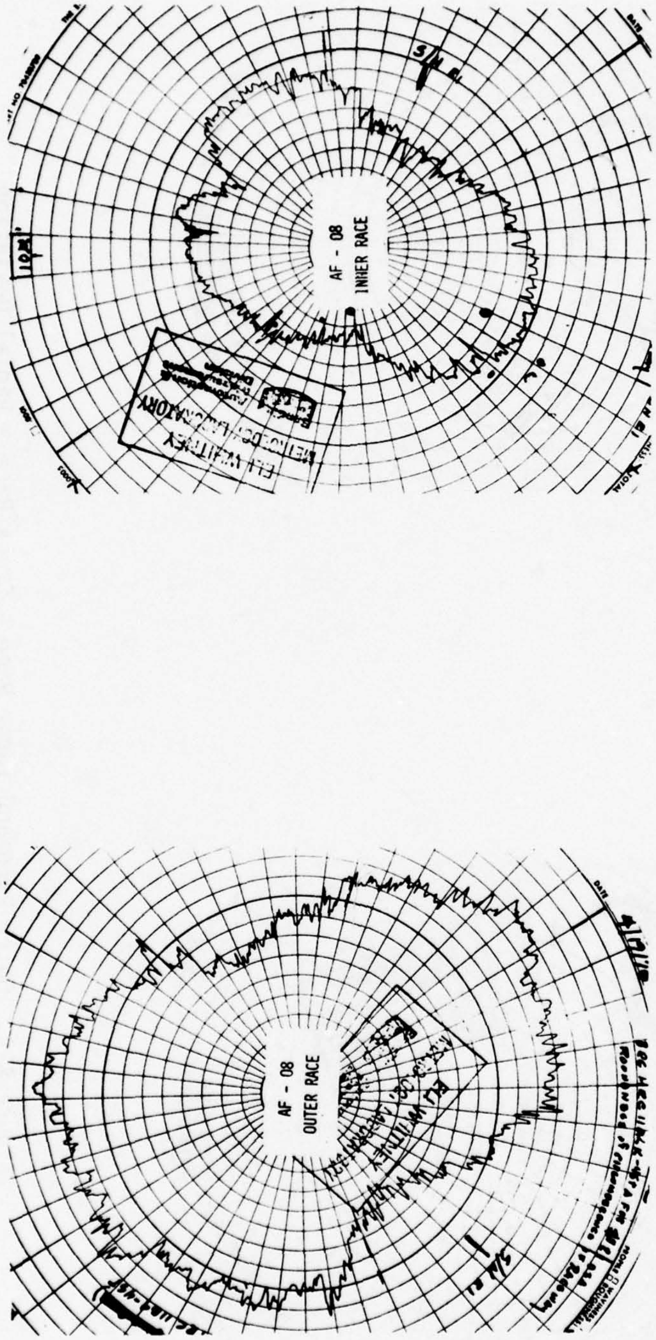


Figure A-3. Outer Race and Inner Race Roundness - Radial Deviation

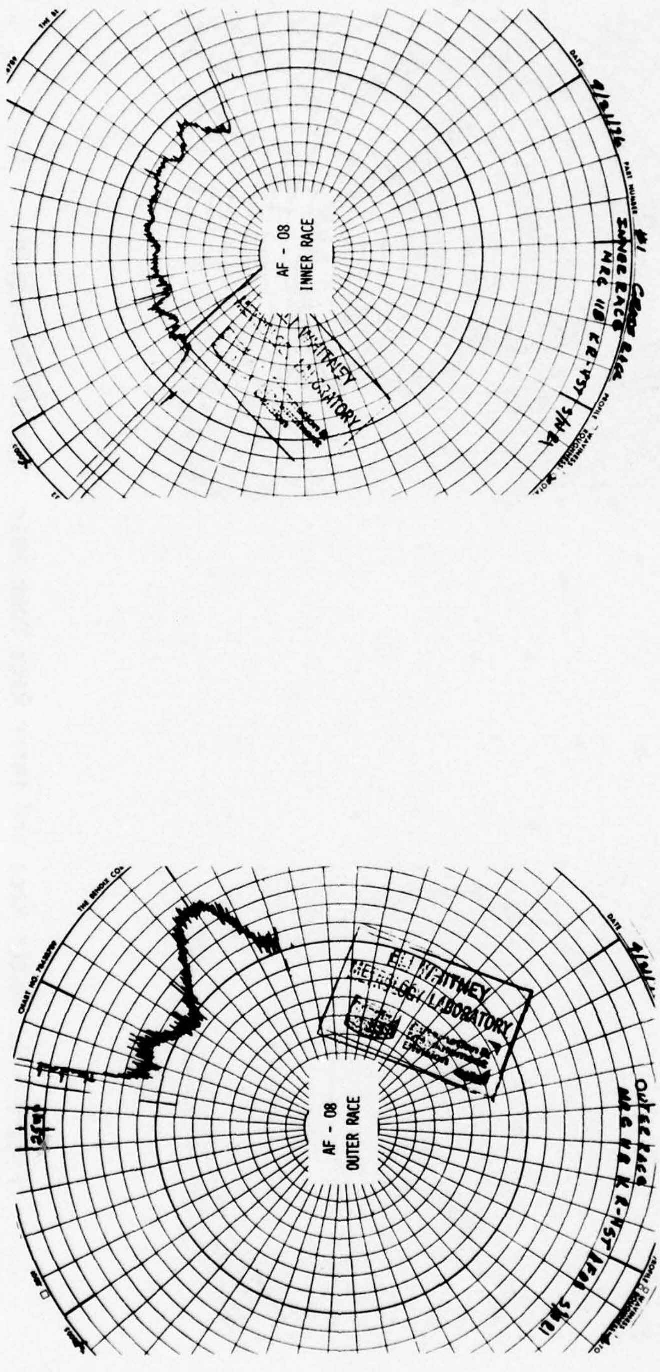


Figure A-4. Outer Race and Inner Race - Cross Race - Radial Deviation

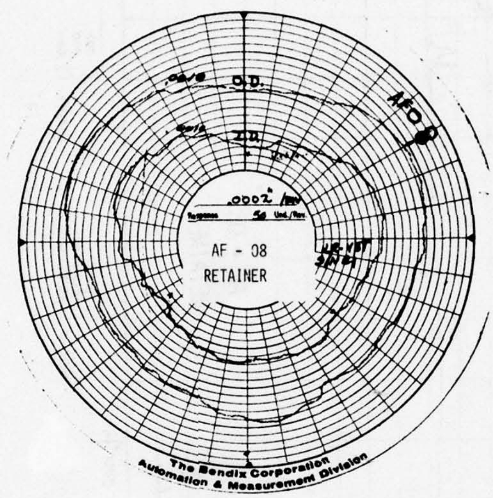


Figure A-5. Retainer - Roundness - Radial Deviation I.D. and O.D.

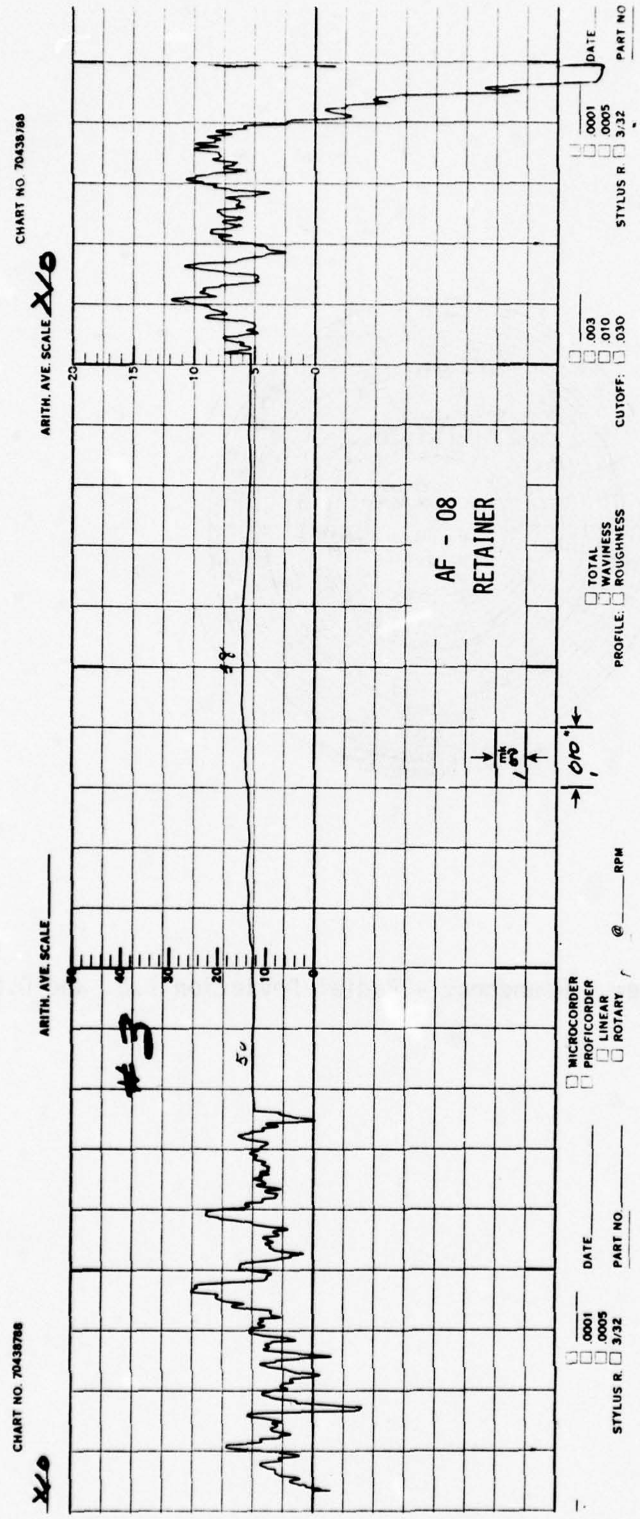


Figure A-6. Retainer Pocket - Roughness

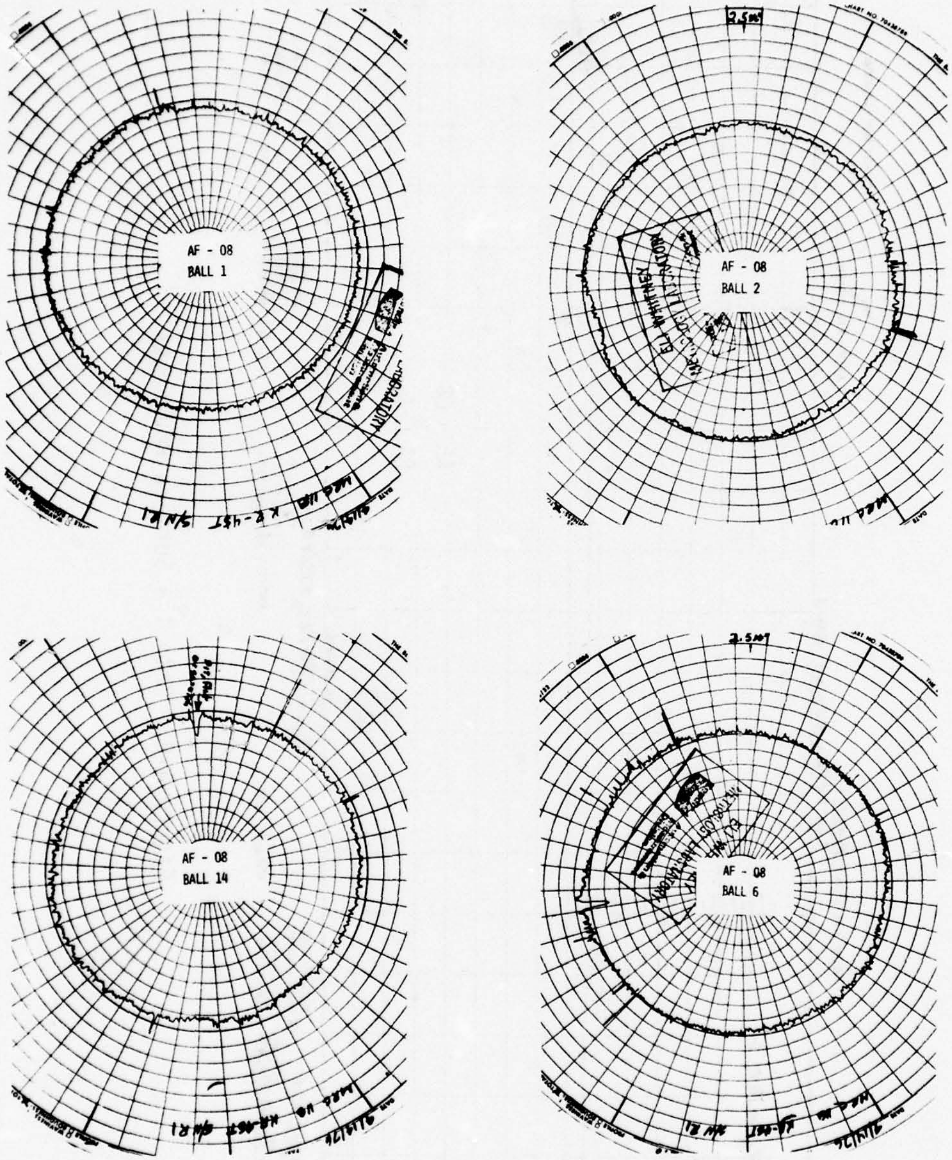


Figure A-7. Balls 1, 2, 14 and 6 - Roundness - Radial Deviation

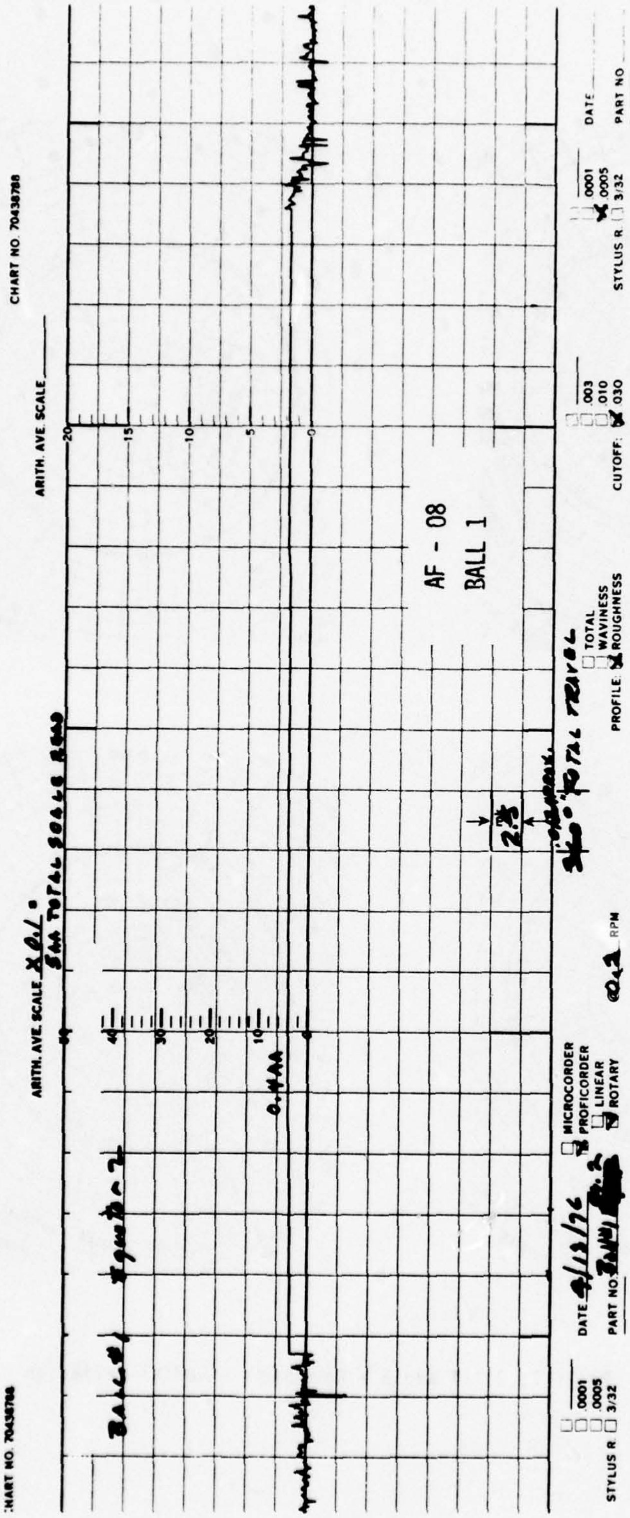


Figure A-8. Ball 1 - Surface Roughness

APPENDIX B - BEARING B

The description and complete metrology data for Bearing B is presented herewith:

Description:

AFML ID #	:	AF-23
ABEC Grade	:	7
Surface Finish	:	3-4 μ in. (nominal)
Bore	:	90 mm
O.D.	:	140 mm
Width	:	24 mm
Contact Angle	:	26 ± 1 degree
Cage Guide	:	Inner Race
No. of Balls	:	21
Ball Diameter	:	14.3 mm (.5625 in.)
Ball/Race Material	:	52100 steel
Retainer ID #	:	AF-13
Retainer Material	:	Bakelite
Retainer Porosity	:	-

Metrology:

This data was obtained through the Eli Whitney Metrology Laboratory, Bendix Automation and Measurement Division, Dayton, Ohio. For the sake of brevity, the complete set of polar graphs illustrating the radial deviation of roundness of all the balls is not presented. Those graphs of balls which are presented are representative of the entire complement and/or illustrate a surface defect of note. For example, in Figure B-7, Ball 1 is the best ball; Ball 19 is the worst ball; Ball 5 shows a single pit, flat or scratch; and Ball 9 shows two pits or scratches with high spots in between them.

Because of the obvious differences in the polar graphs of the balls in this bearing as compared to Bearing A, it was decided to clean two of the balls and re-accomplish the polar graphs after cleaning to determine whether there was surface contamination present on the balls in Bearing B.

Ball #19 was cleaned in the following manner:

Boiling Freon	-	10 minutes
Boiling Ethanol	-	10 minutes
Boiling Acetone	-	10 minutes
Chromerge	-	3 minutes
Distilled Water	-	Several Rinses
Boiling Acetone	-	10 minutes
Boiling Ethanol	-	10 minutes
Boiling Freon	-	10 minutes

As a precaution against the deleterious effects of Chromerge on 52100 steel, i.e. corrosion, Ball #4 (Figure B-9 - Left) was cleaned utilizing only the first three solvent cleaning steps. Figures B-9 (Right) and B-10 are polar graphs of Ball #4 and Ball #19 respectively after cleaning. As can be seen, there is no substantial improvement in either ball as a result of cleaning and one must conclude that the real ball surfaces are as rough as they appear to be.

One interesting aspect of these comparisons is that although the balls of Bearing B appear to have poorer quality surface finishes than Bearing A, the surface finish (AA) of the balls of both bearings is almost the same i.e., 0.4 AA μ in. for Bearing A and 0.3-0.5 AA μ in. for Bearing B.

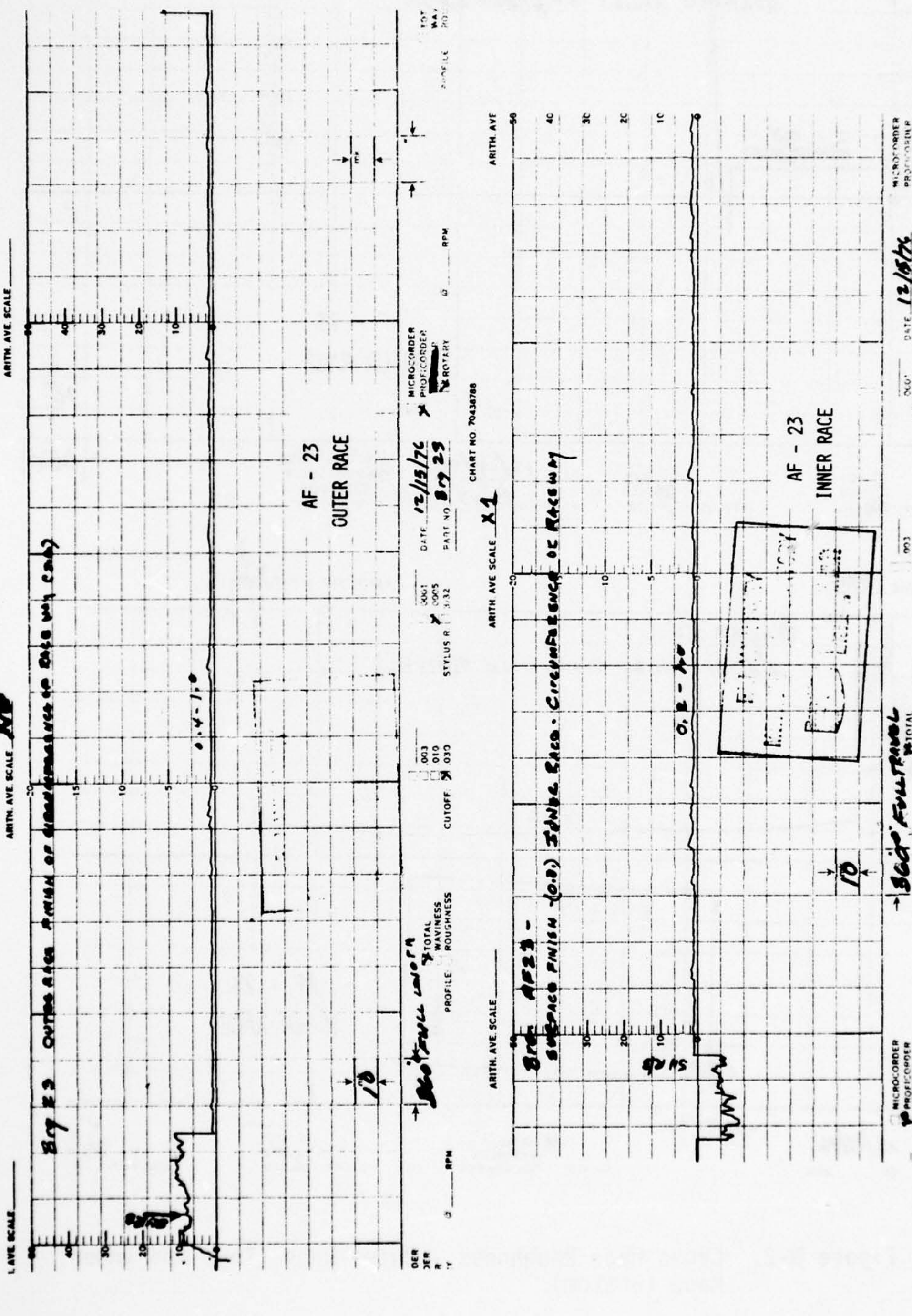


Figure B-1. Circumferential Roughness - Outer Race (Top) and Inner Race (Bottom)

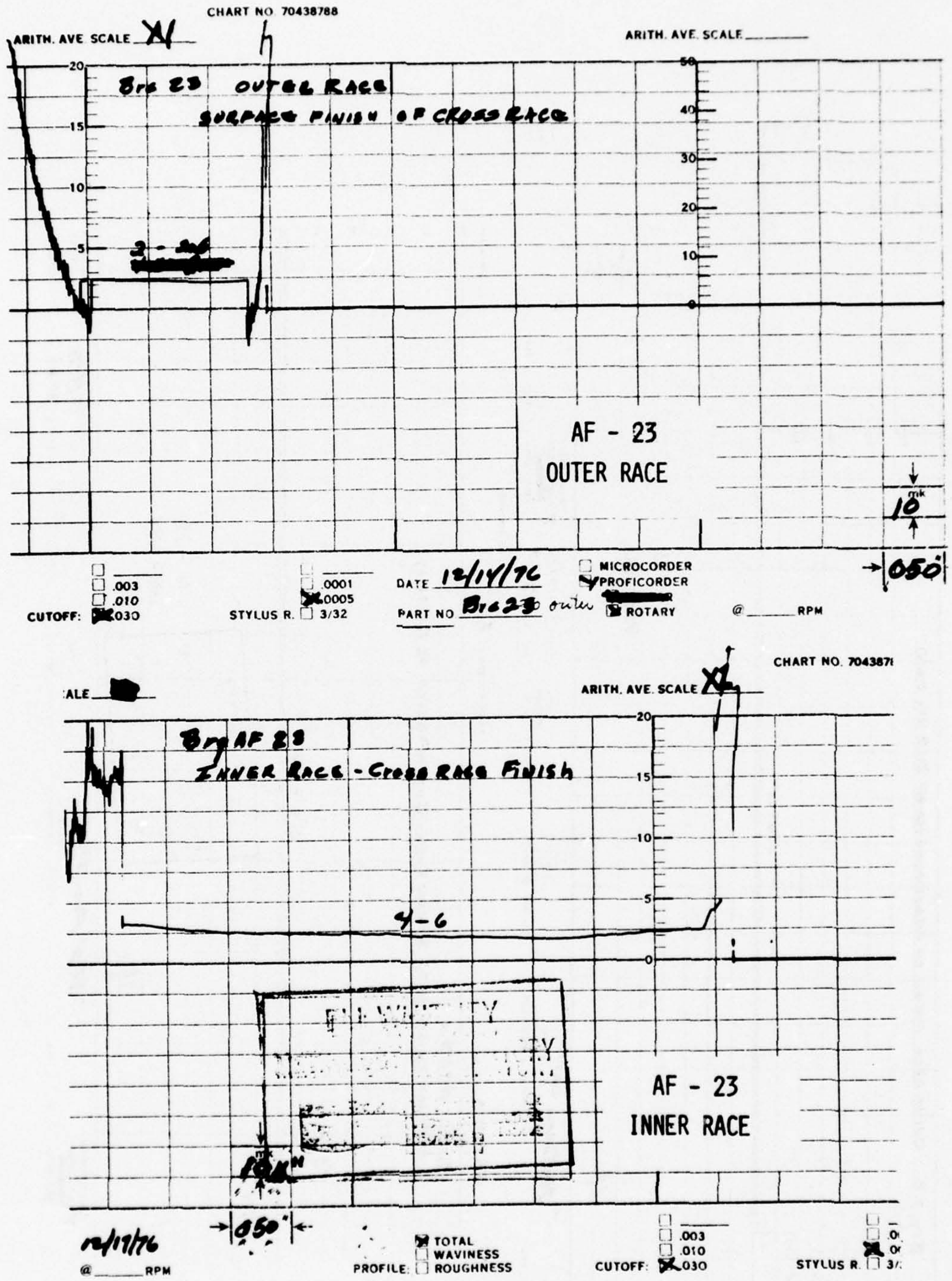


Figure B-2. Cross Race Roughness - Outer Race (Top) and Inner Race (Bottom)

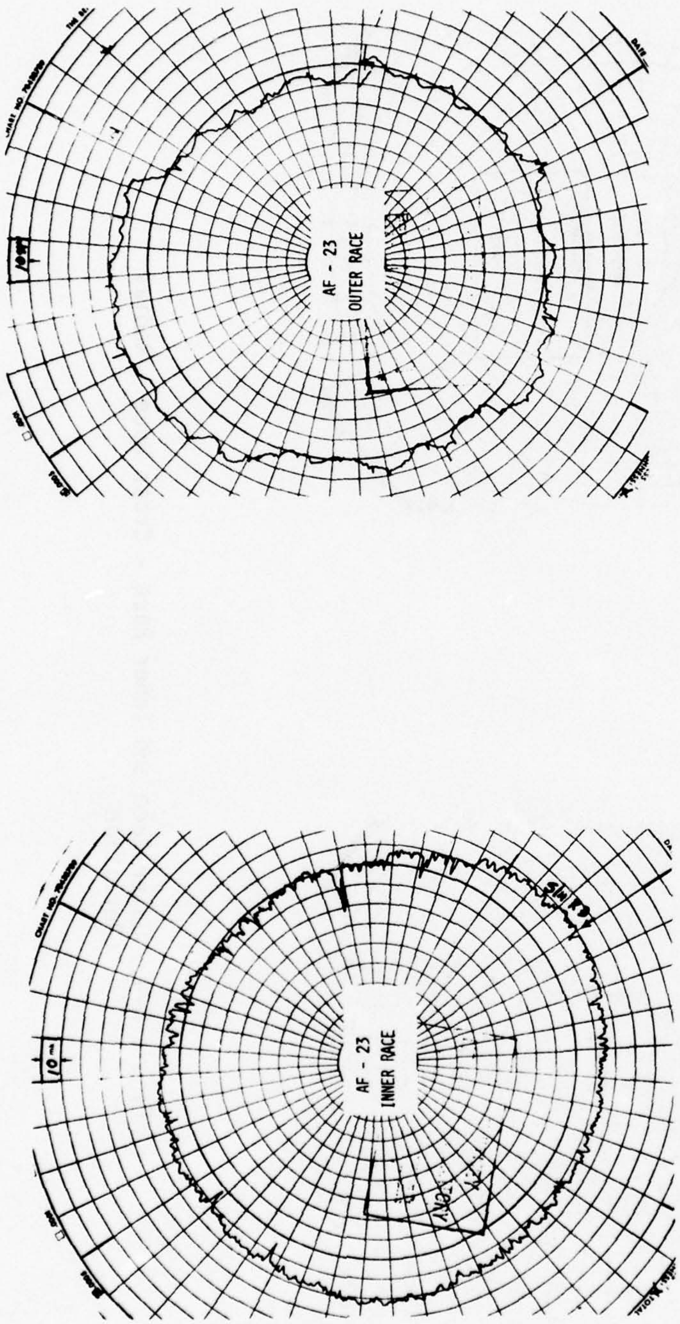
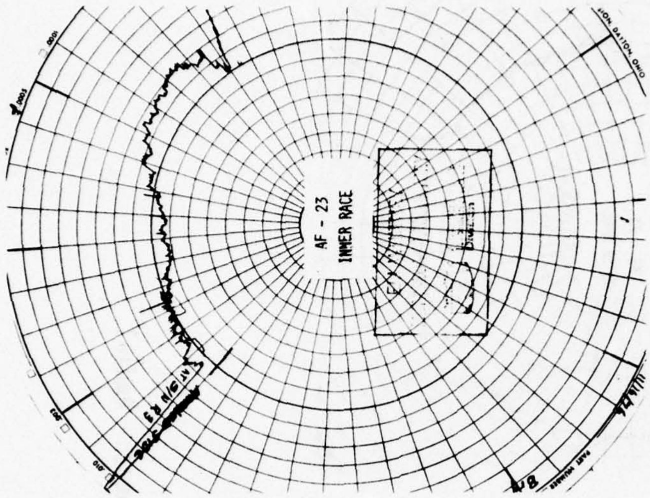


Figure B-3. Outer Race and Inner Race Roundness - Radial Deviation



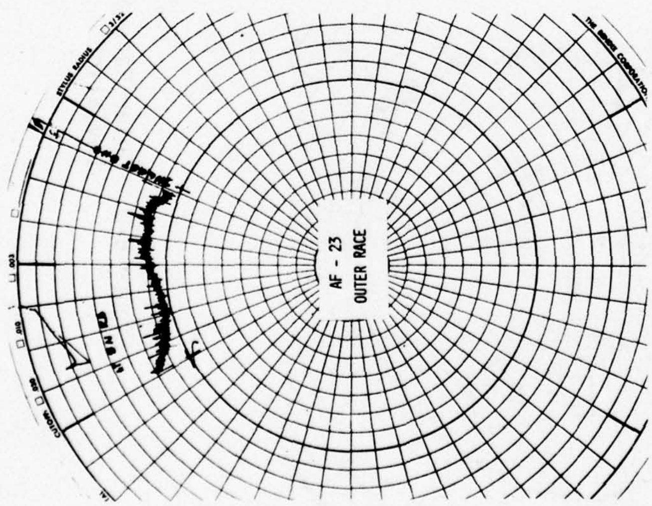


Figure B-4. Outer Race and Inner Race - Cross Race - Radial Deviation

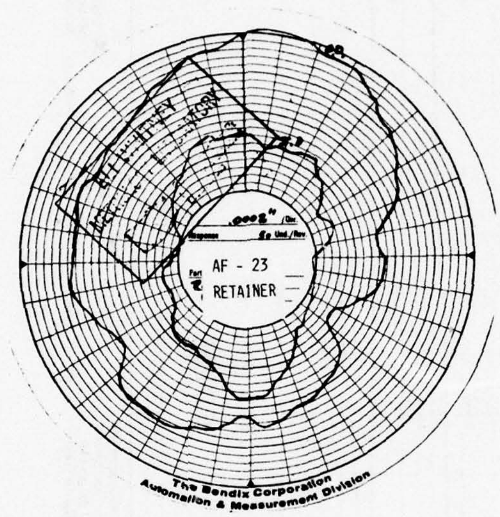


Figure B-5. Retainer - Roundness - Radial Deviation

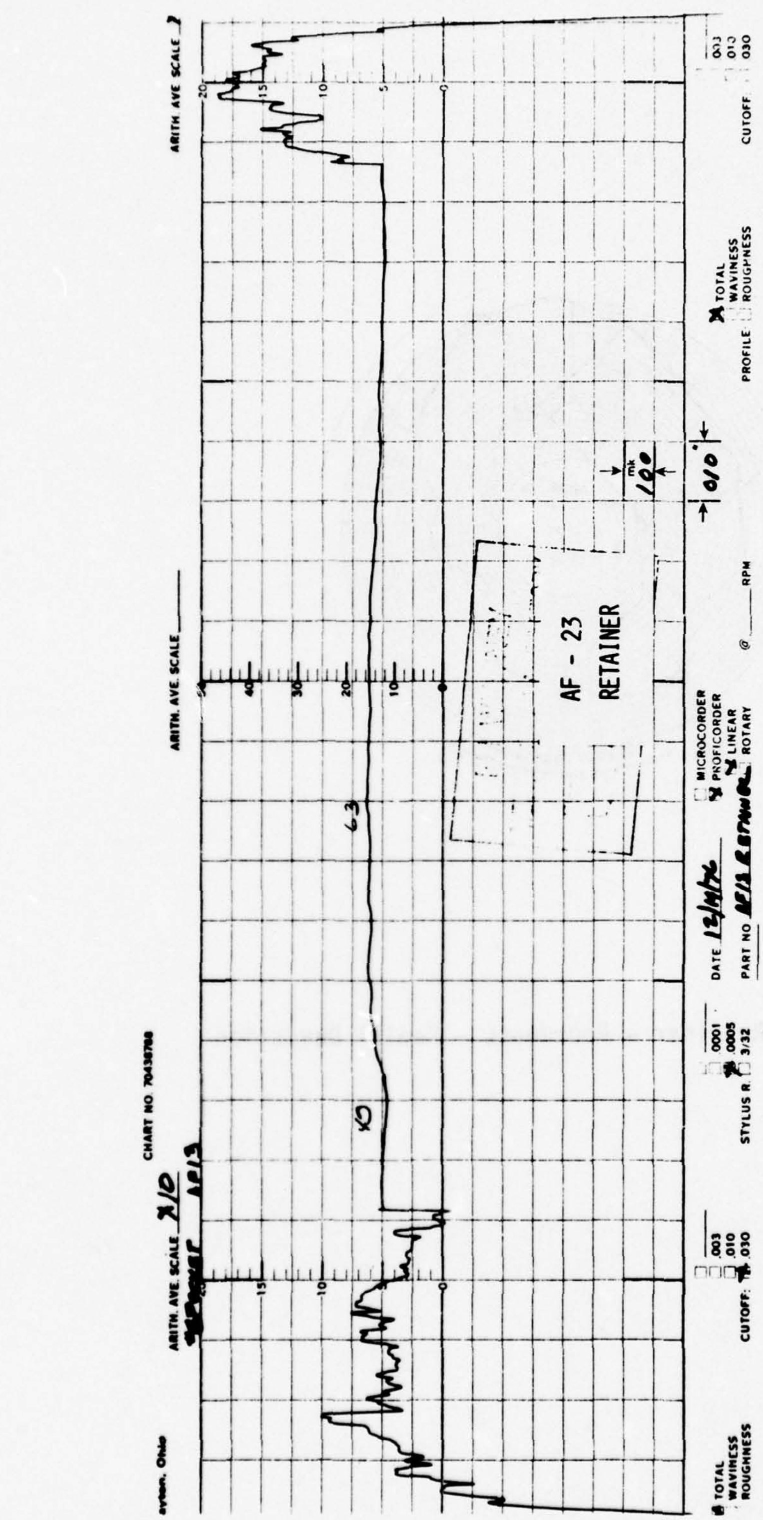


Figure B-6. Retainer Pocket - Roughess

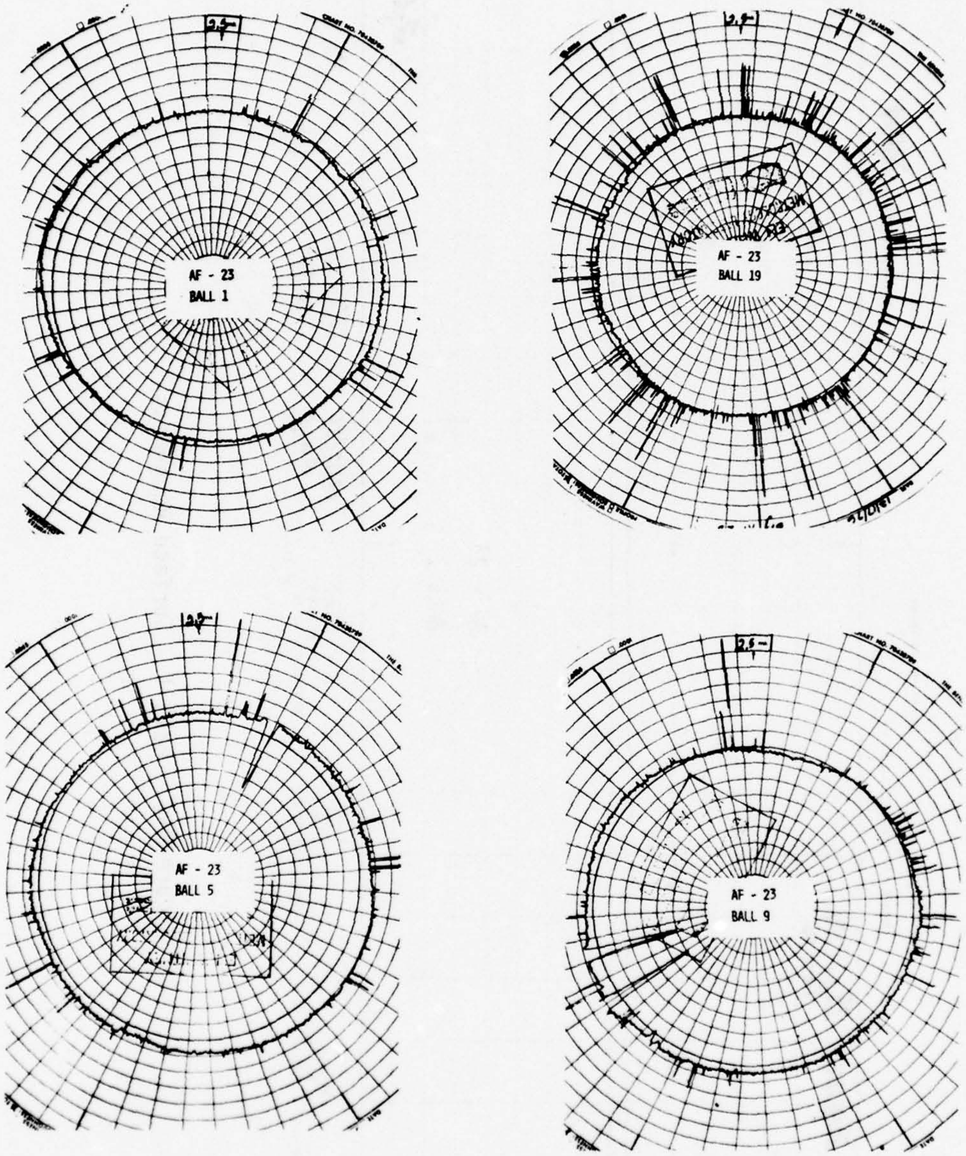


Figure B-7. Balls 1, 19, 5, 9 - Roundness

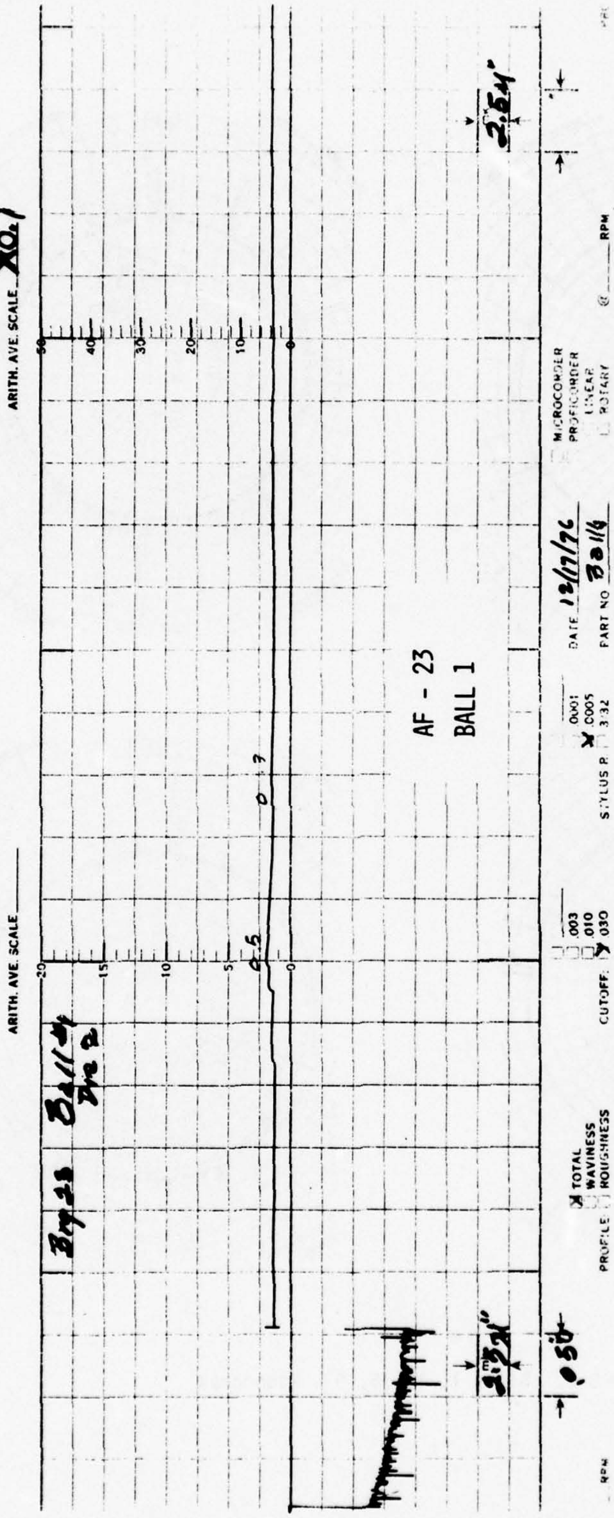


Figure B-8. Ball 1 - Surface Roughness

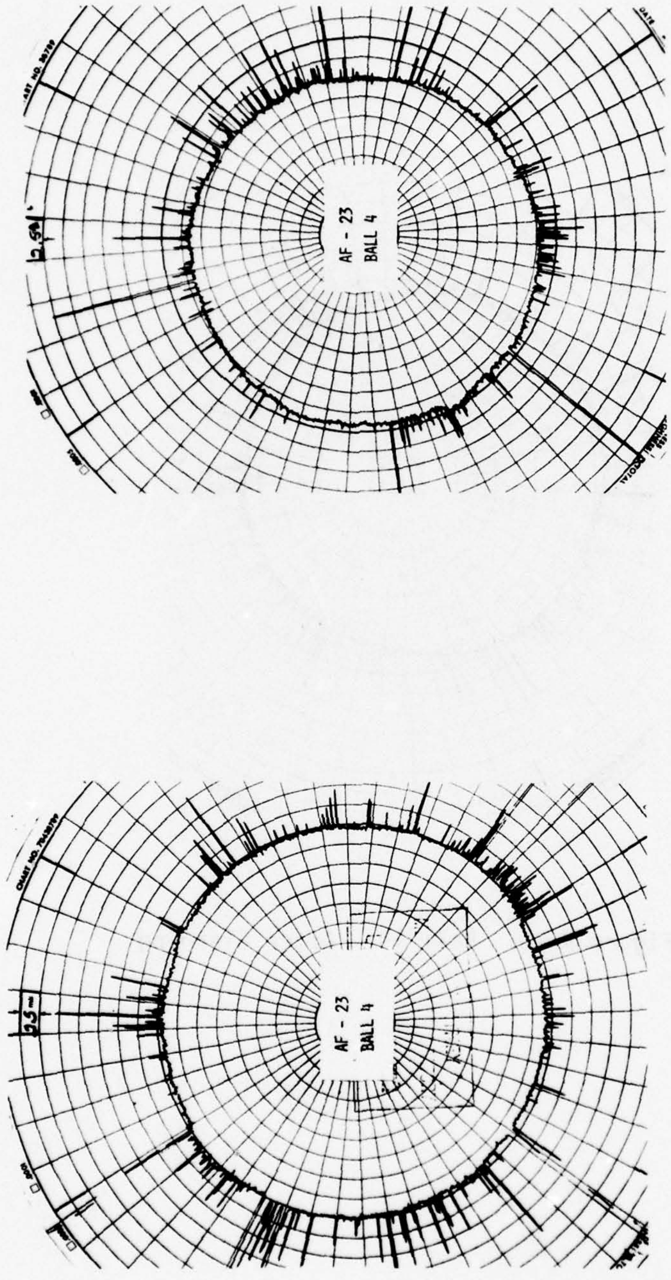


Figure B-9. Ball 4 - Before (Left) and After (Right) Cleaning

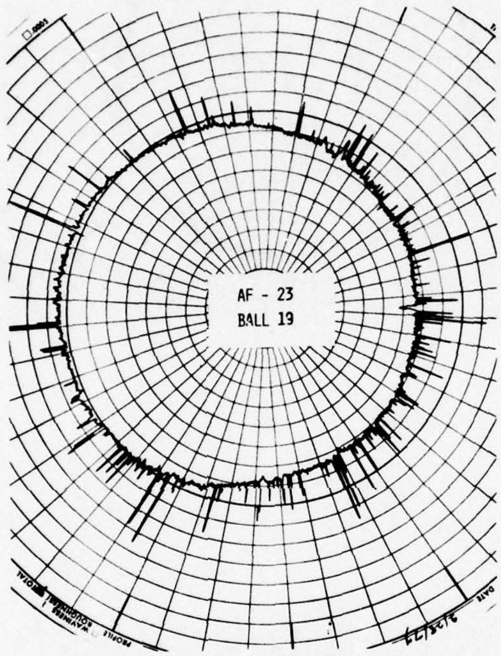


Figure B-10. Ball 19 - After Cleaning

APPENDIX C - BEARING C

The description and complete metrology data for Bearing C is presented herewith:

Description:

AFML ID #	-	AF-21
ABEC Grade	-	7
Surface Finish	-	3-4 μ in. (nominal)
Bore	-	90 mm
O.D.	-	140 mm
Width	-	24 mm
Contact Angle	-	26 ± 1 degree
Cage Guide	-	Inner Race
No. of Balls	-	21
Ball Diameter	-	14.3 mm (.5625 in.)
Ball/Race Material	-	52100 steel
Retainer ID #	-	AF-11
Retainer Material	-	Bakelite
Retainer Porosity	-	-

Metrology:

This data was obtained through the Eli Whitney Metrology Laboratory, Bendix Automation and Measurement Division, Dayton, Ohio. For the sake of brevity, the complete set of polar graphs illustrating the radial deviation of roundness of all the balls is not presented. Those graphs of balls which are presented are representative of the entire complement and/or illustrate a surface defect of note. For example, in Figure C-7, Ball 3 is the best ball; Ball 18 shows the typically poor surface finish; Ball 2 shows a severe pit or scratch; and Ball 16 has some large high spots.

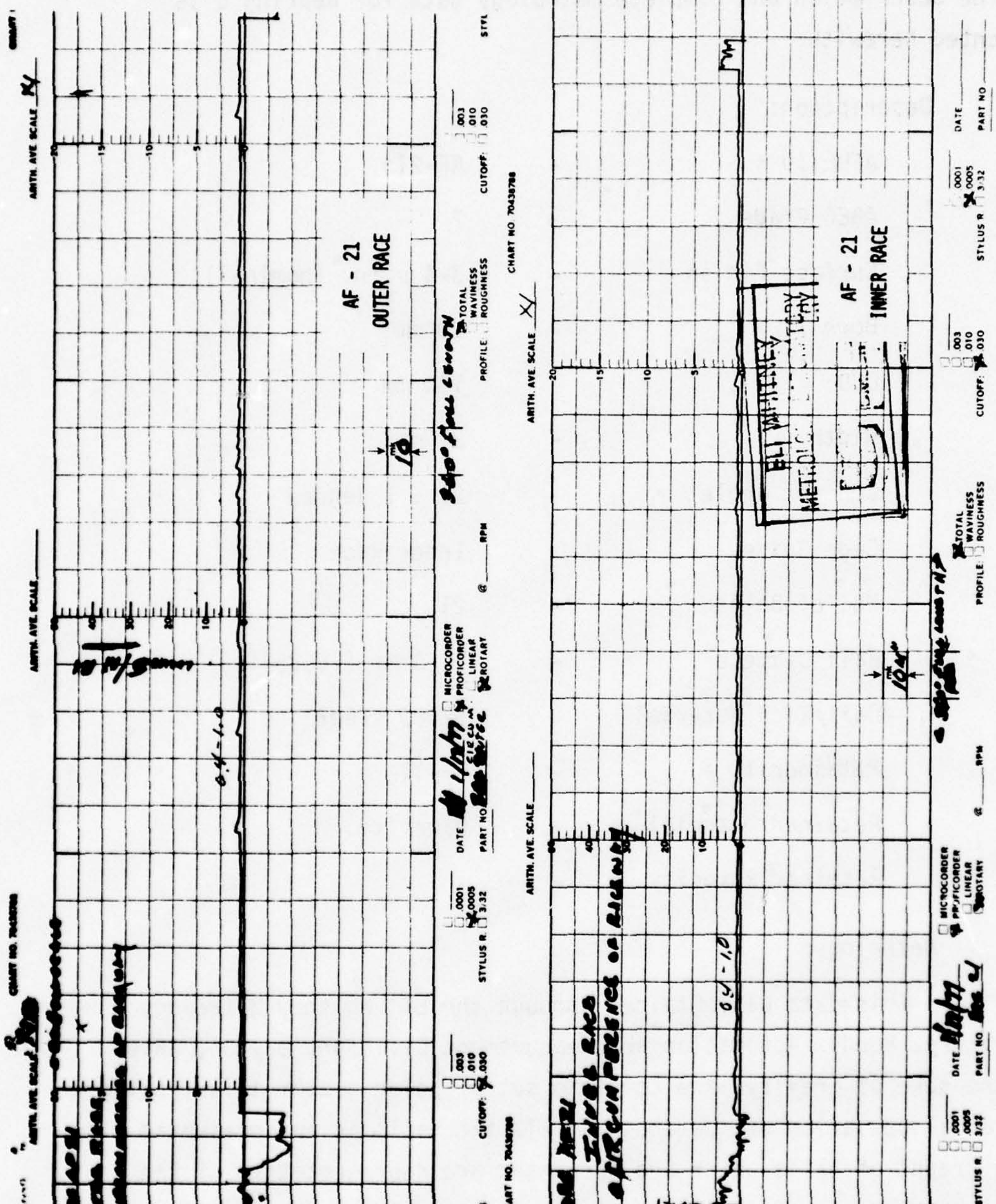
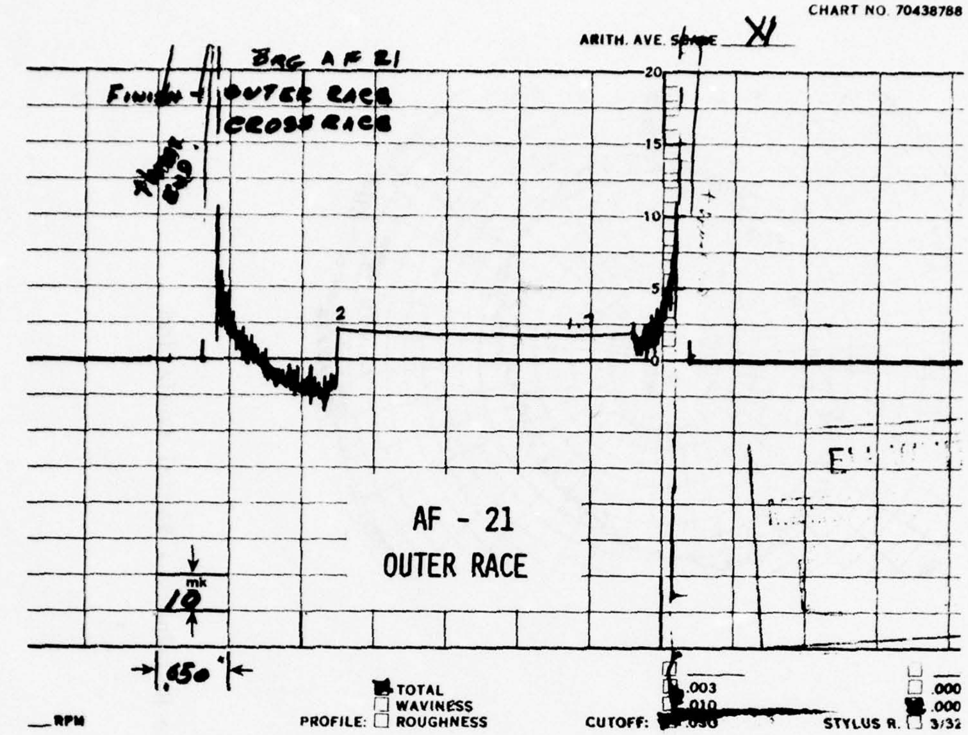


Figure C-1. Circumferential Roughness - Outer Race (Top) and Inner Race (Bottom)



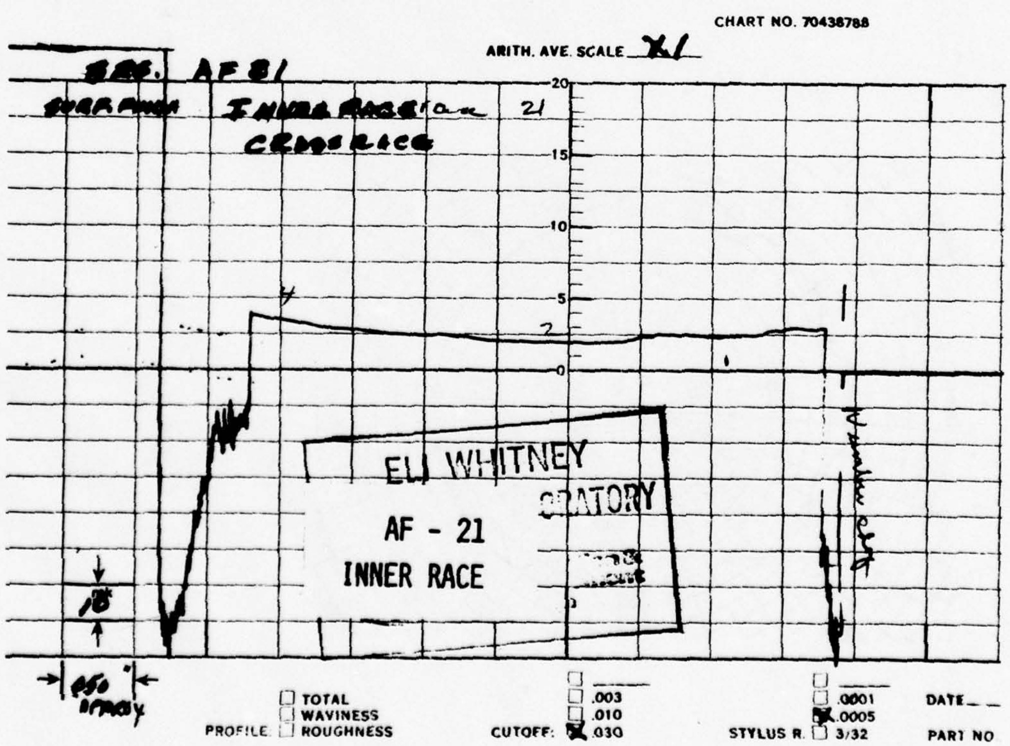
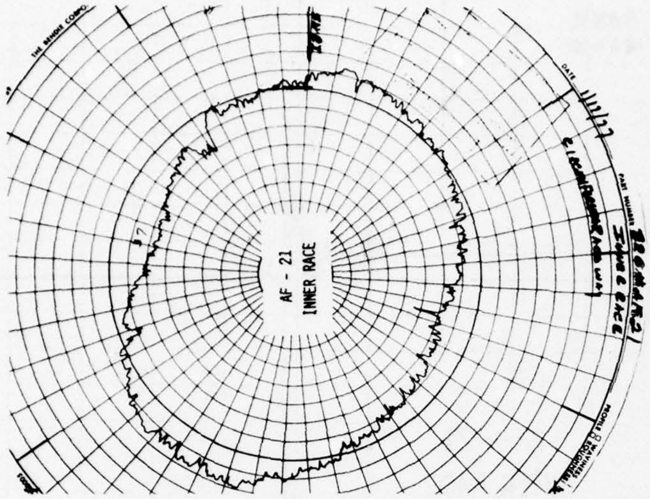


Figure C-2. Cross Race Roughness - Outer Race (Top) and Inner Race (Bottom)



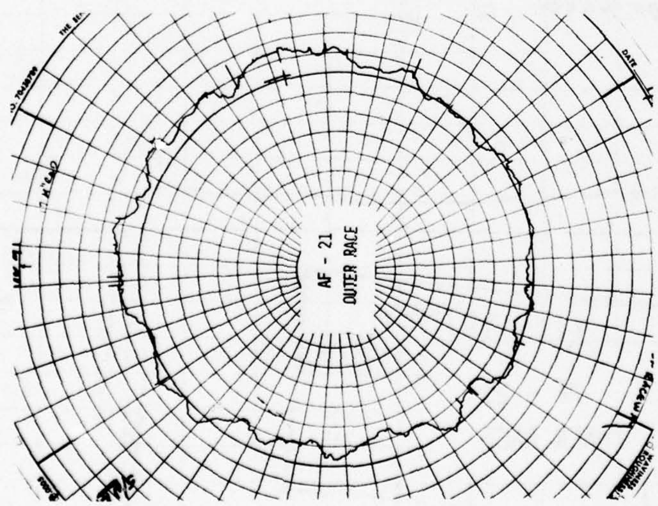


Figure C-3. Outer Race and Inner Race Roundness - Radial Deviation

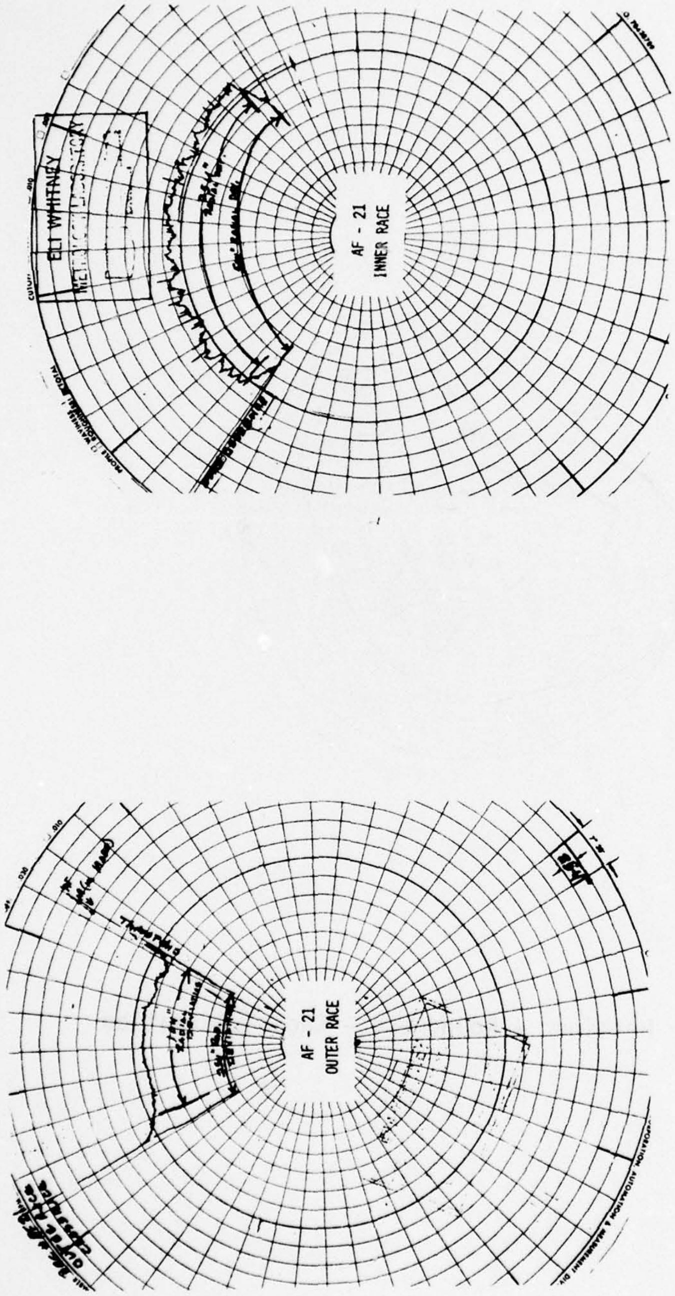


Figure C-4. Outer Race and Inner Race - Cross Race - Radial Deviation

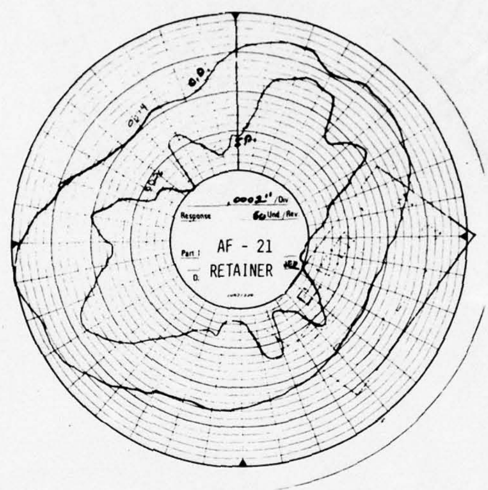


Figure C-5. Retainer - Roundness - Radial Deviation

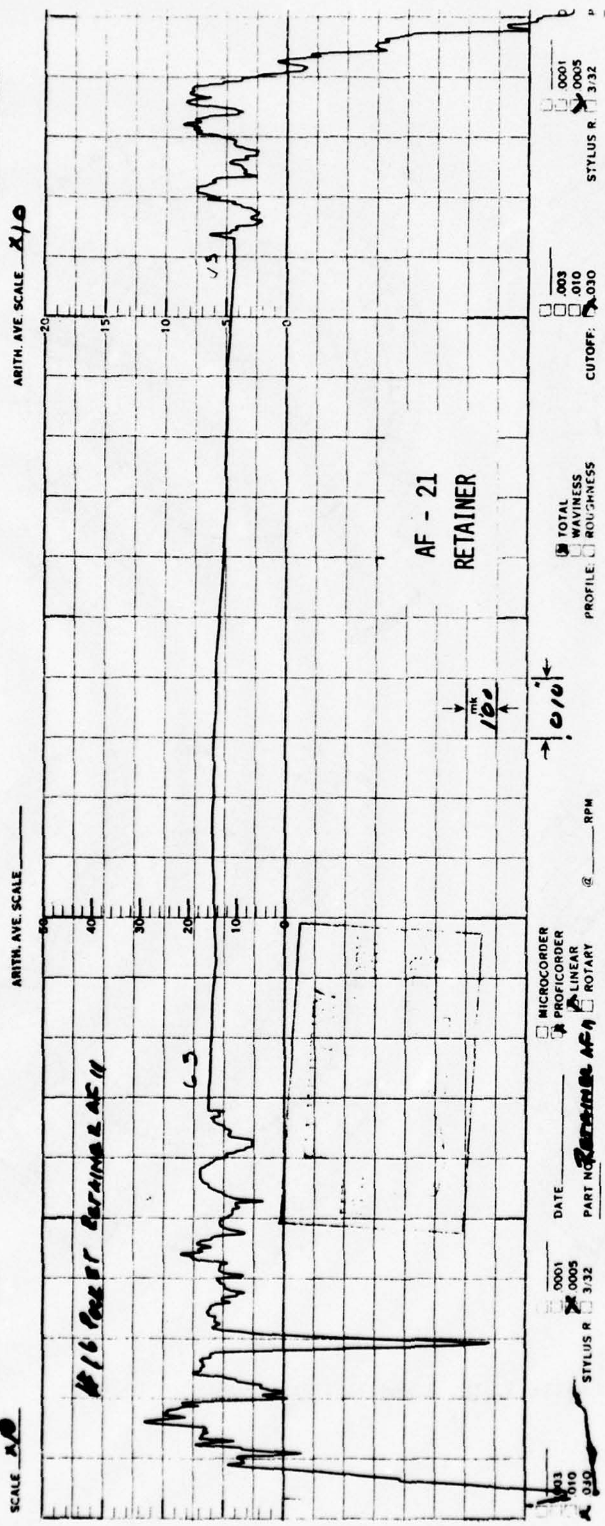


Figure C-6. Retainer Pocket - Roughness

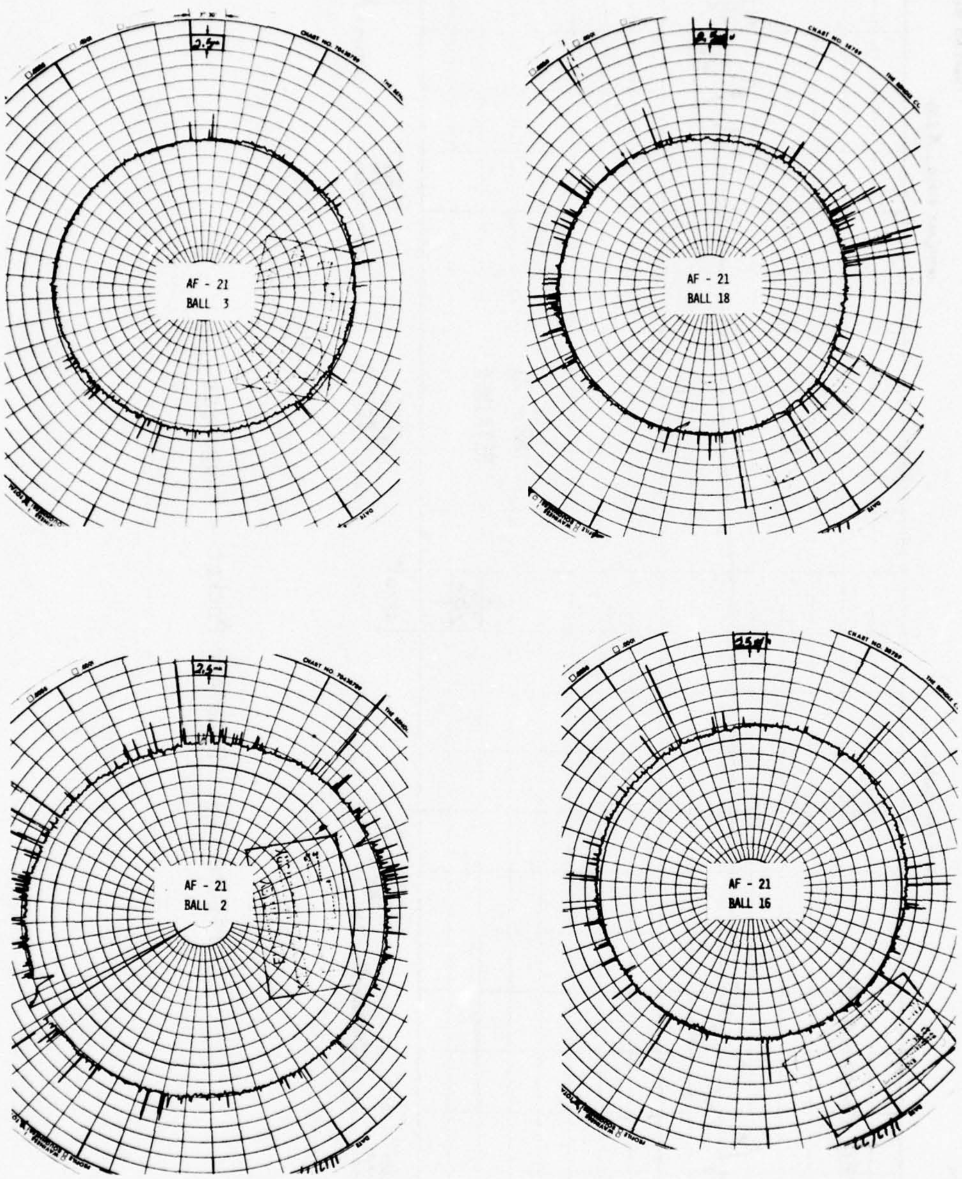


Figure C-7. Balls 3, 18, 2 and 16 - Roundness

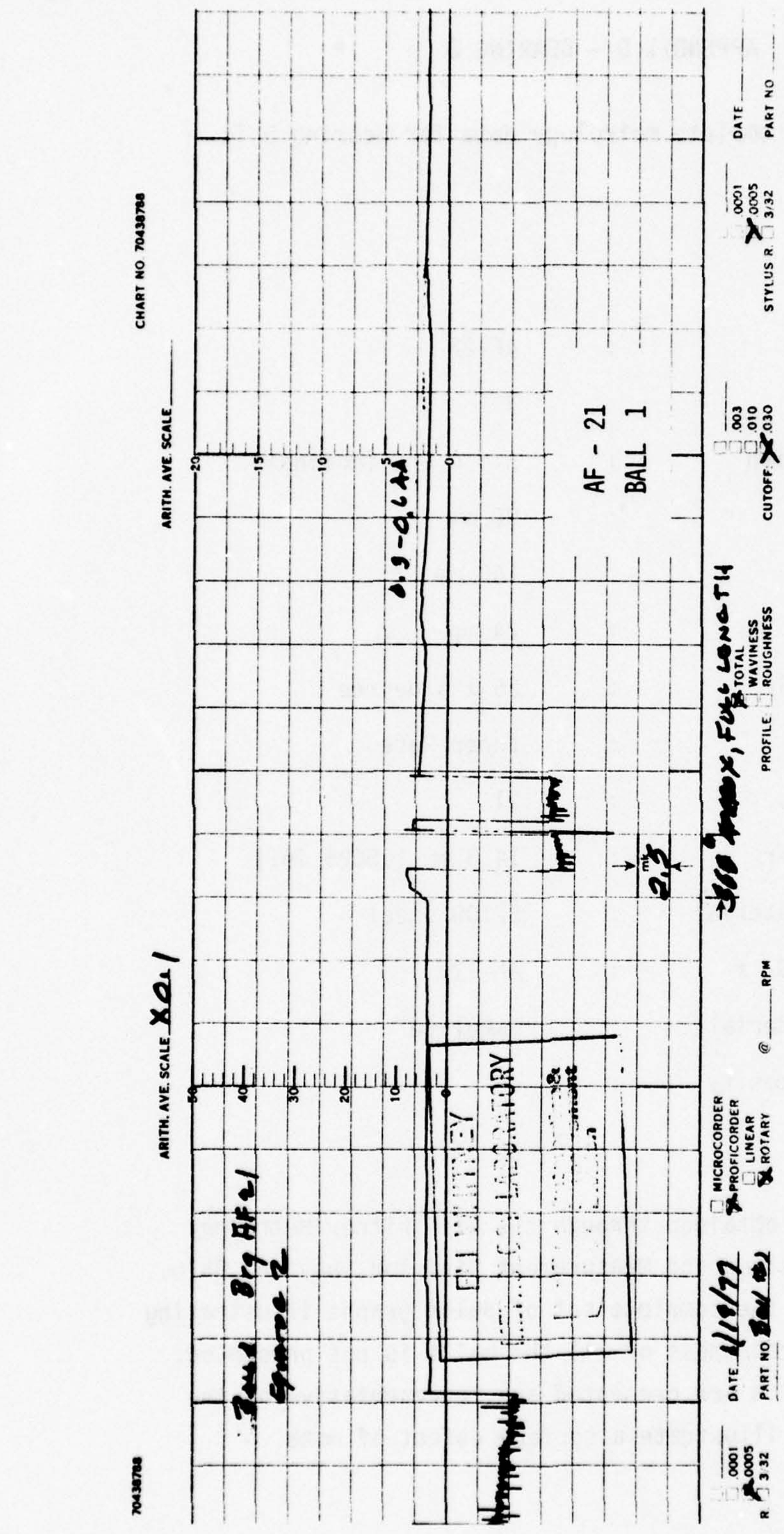


Figure C-8. Ball 1 - Surface Roughness

APPENDIX D - BEARING D

The description and complete metrology data for Bearing D is present herewith:

Description:

AFML I.D. #	:	AF-22
ABEC Grade	:	7
Surface Finish	:	3-4 μ in. (nominal)
Bore	:	90 mm
O.D.	:	140 mm
Width	:	24 mm
Contact Angle	:	26 ± 1 degree
Cage Guide	:	Inner Race
No. of Balls	:	21
Ball Diameter	:	14.3 mm (.5625 in.)
Ball/Race Material	:	52100 steel
Retainer I.D. #	:	AF-12
Retainer Material	:	Bakelite
Retainer Porosity	:	-

Metrology:

This data was obtained through the Eli Whitney Metrology Laboratory, Bendix Automation and Measurement Division, Dayton, Ohio. For the sake of brevity, the complete set of polar graphs illustrating the radial deviation of roundness of all the balls is not presented. Those graphs of balls which are presented are representative of the entire complement and/or illustrate a surface defect of note.

For example, in Figure D-7, Ball 13 is a good ball; Ball 2 shows the typically poor surface finish; Ball 21 shows severe out of roundness; and Ball 14 shows the typical pit, flat or scratch.

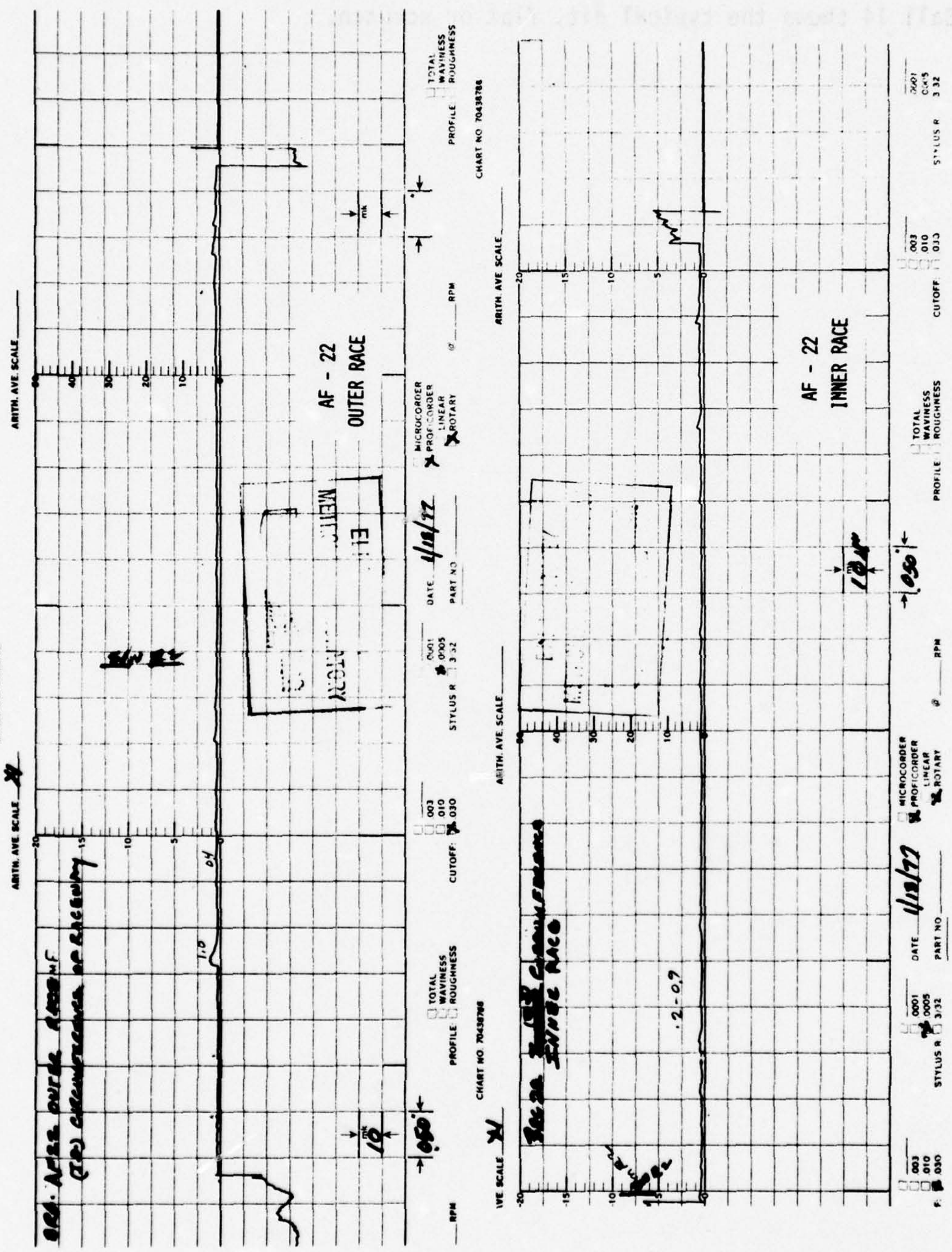
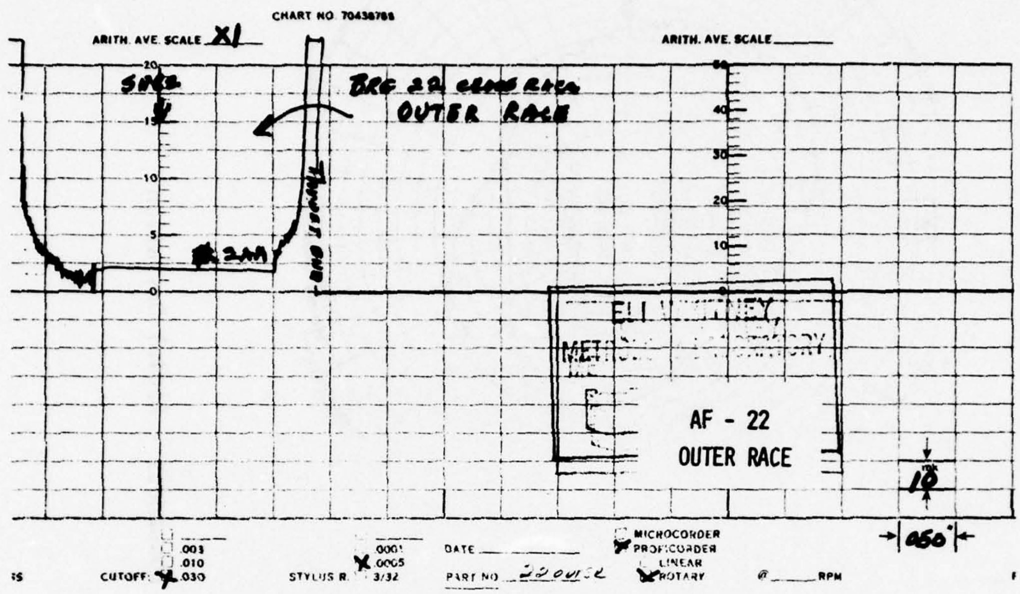


Figure D-1. Circumferential Roughness - Outer Race (Top) and Inner Race (Bottom)



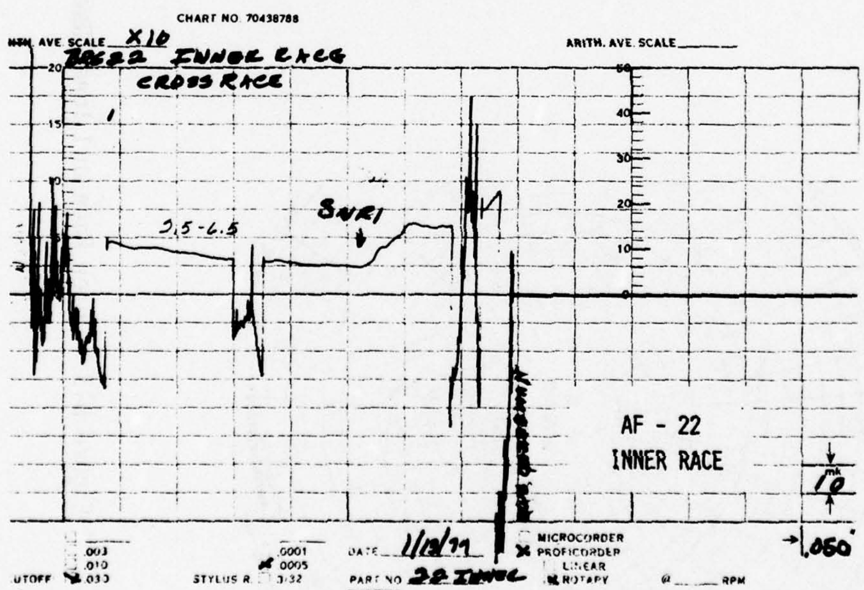
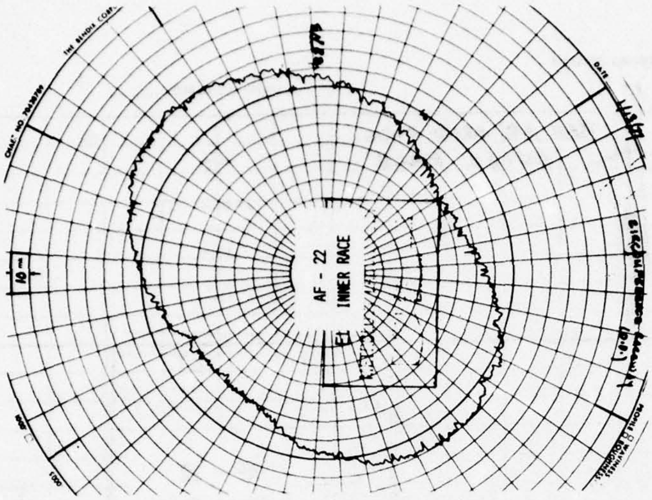


Figure D-2. Cross Race Roughness - Outer Race (Top) and Inner Race (Bottom)



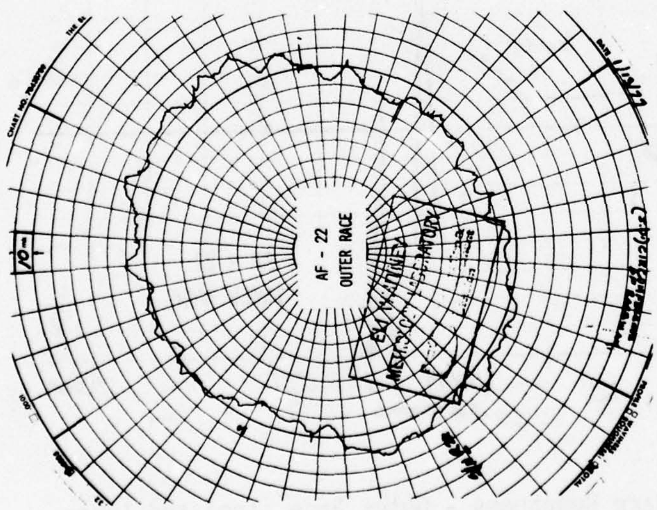


Figure D-3. Outer Race and Inner Race Roundness - Radial Deviation

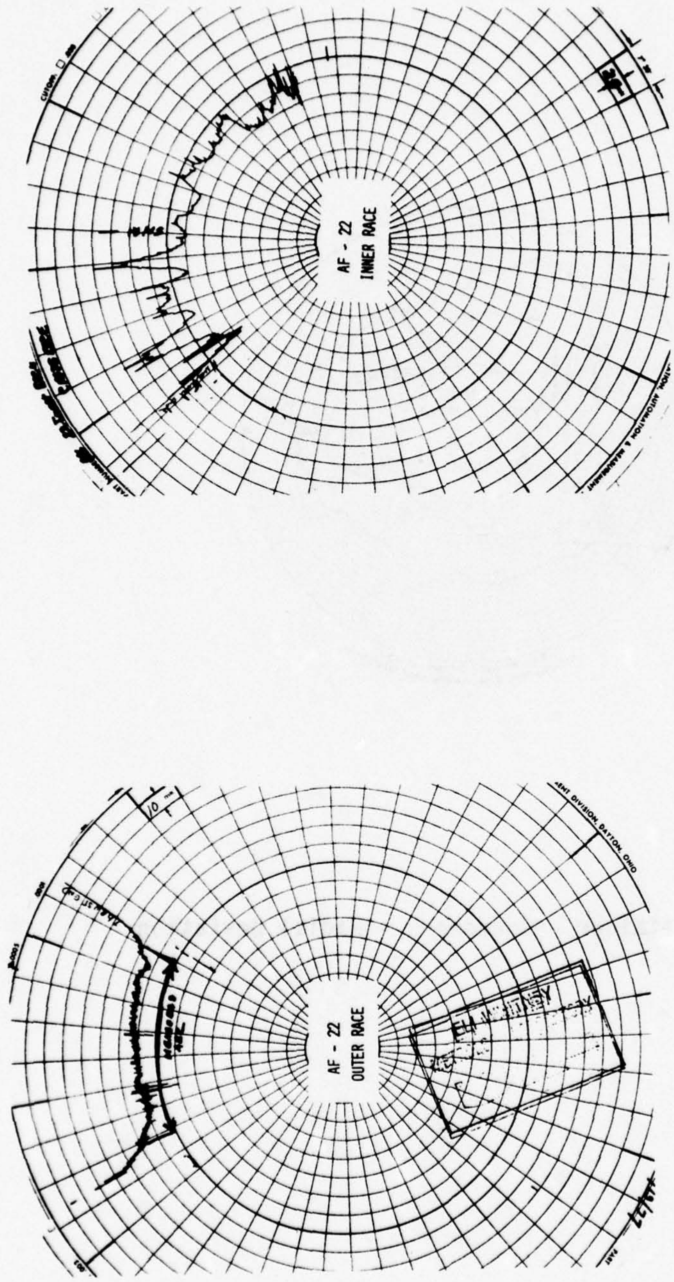


Figure D-4. Outer Race and Inner Race - Cross Race - Radial Deviation

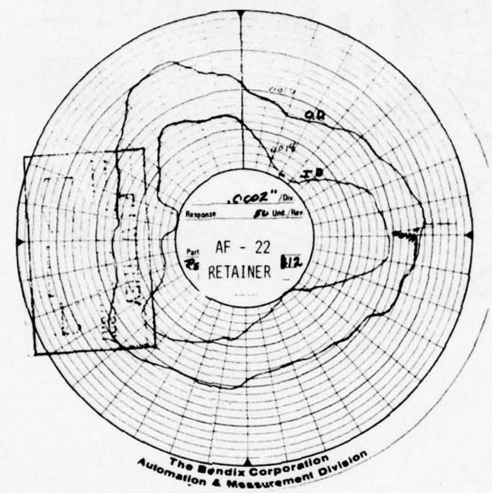


Figure D-5. Retainer - Roundness - Radial Deviation

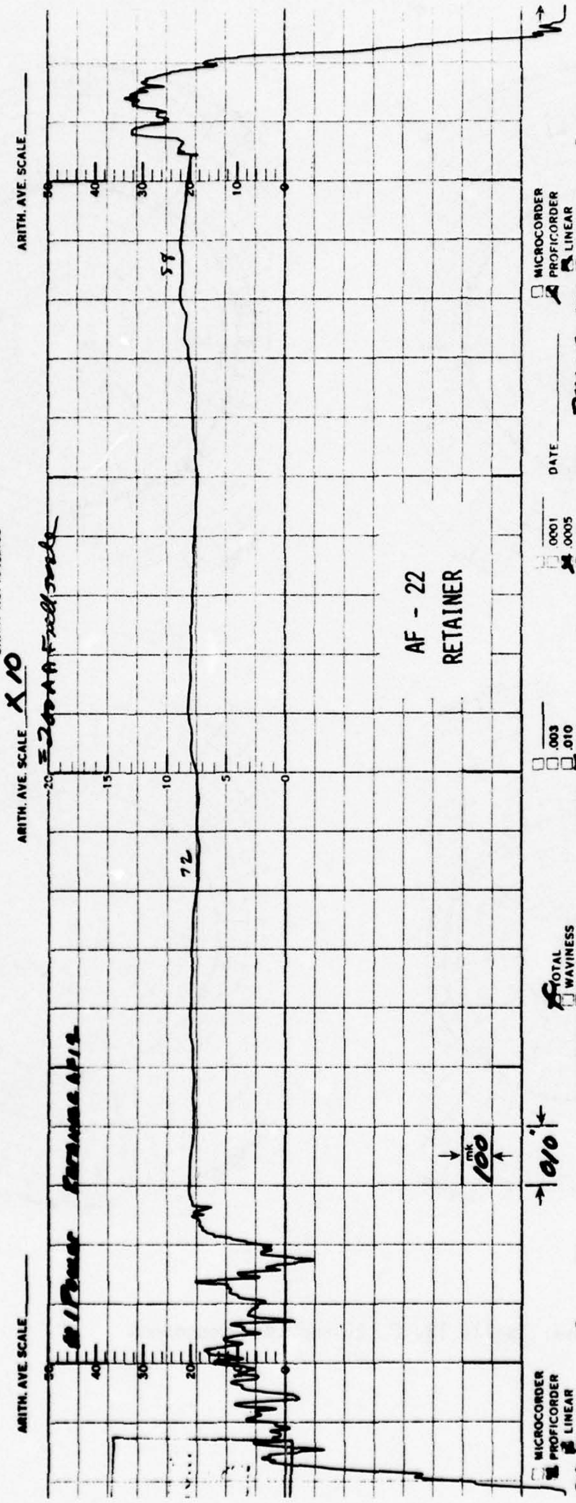


Figure D-6. Retainer Pocket - Roughness

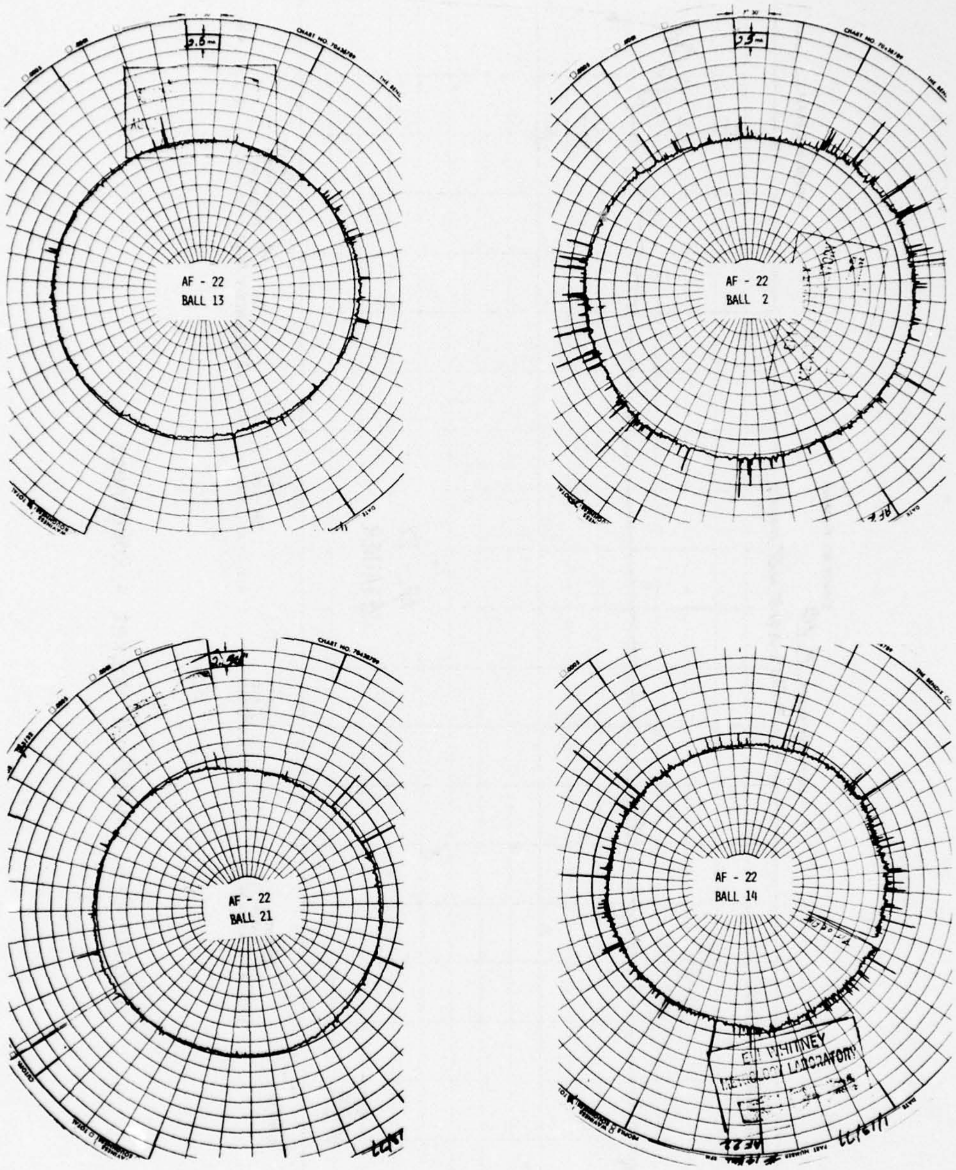


Figure D-7. Balls 13, 2, 21 and 14 - Roundness

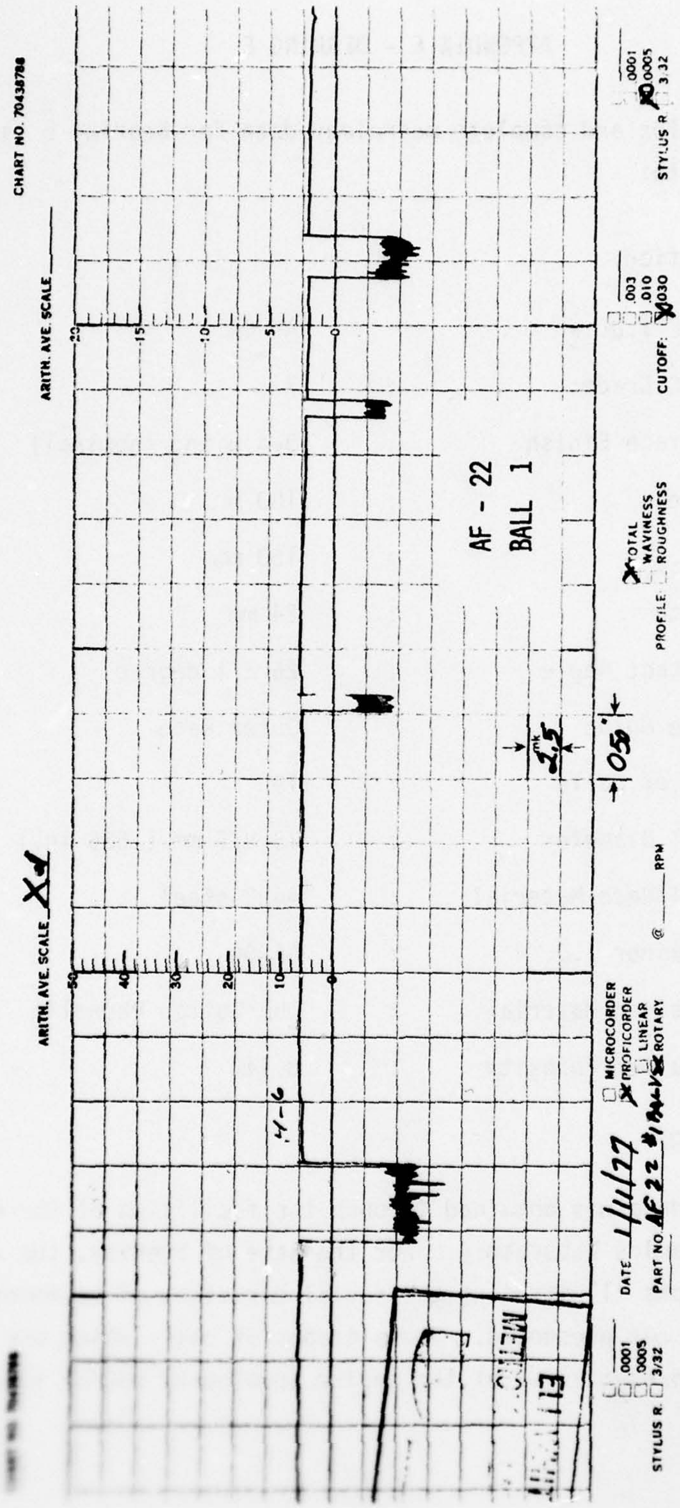


Figure D-8. Ball 1 - Surface Roughness

APPENDIX E - BEARING E

The description and complete metrology data for Bearing E is presented herewith:

Description:

AFML I.D. #	:	AF-04
ABEC Grade	:	7
Surface Finish	:	3-4 μ in. (nominal)
Bore	:	100 mm
O.D.	:	150 mm
Width	:	24 mm
Contact Angle	:	26 $\pm$ 1 degree
Cage Guide	:	Outer Race
No. of Balls	:	19
Ball Diameter	:	15.875 mm (.625 in.)
Ball/Race Material	:	440C steel
Retainer I.D. #	:	AF-04
Retainer Material	:	LBB Cotton Phenolic
Retainer Porosity	:	8.14%

Metrology:

This data was obtained through the facilities of the Air Force Flight Dynamics Laboratory. For the sake of brevity, the complete set of polar graphs illustrating the radial deviation of roundness of all the balls is not presented. Those graphs of balls which are presented are representative of the entire complement and/or illustrate

a surface defect of note. For example, in Figure E-3, Ball 19 shows almost perfect roundness with excellent surface finish; Ball 6 shows equally good roundness, but with a slightly poorer surface finish; Ball 1 shows the most severe out of roundness with some scratches and high spots; and Ball 16 shows the poorest surface finish.

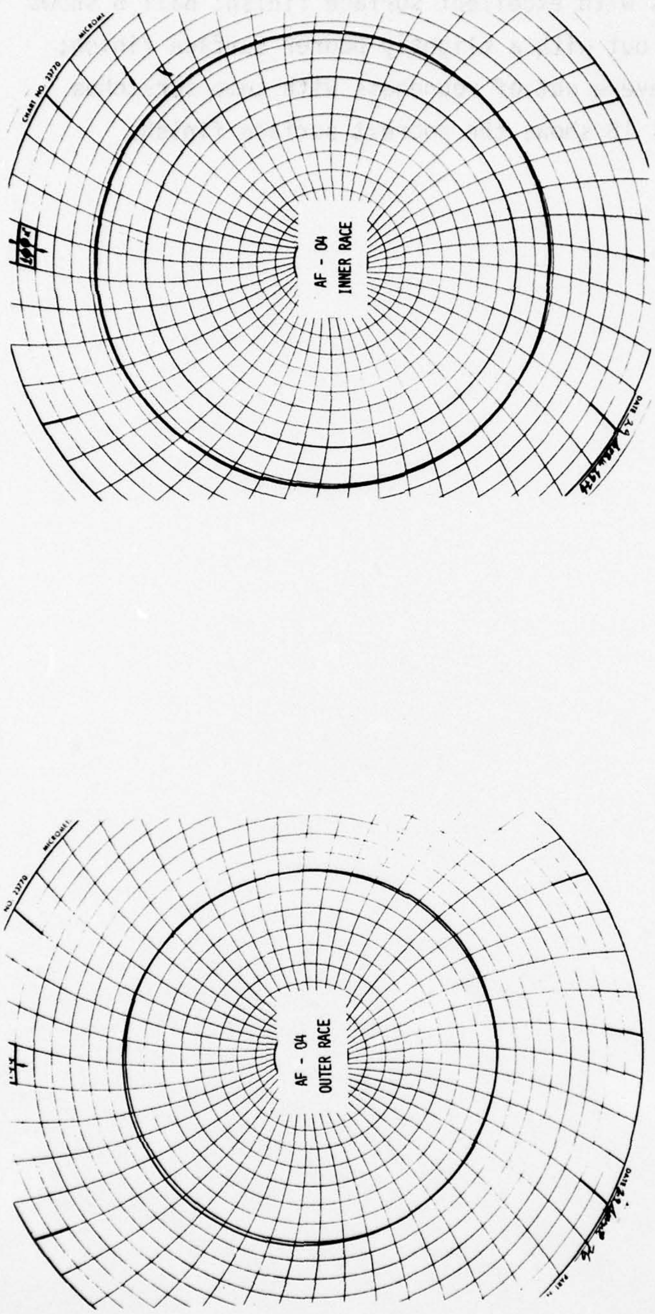


Figure E-1. Outer Race and Inner Race - Roundness - Radial Deviation

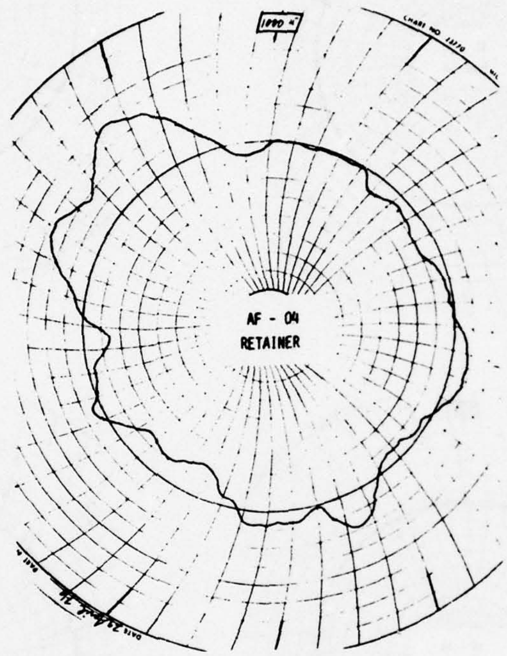


Figure E-2. Retainer - Roundness - Radial Deviation - O.D.

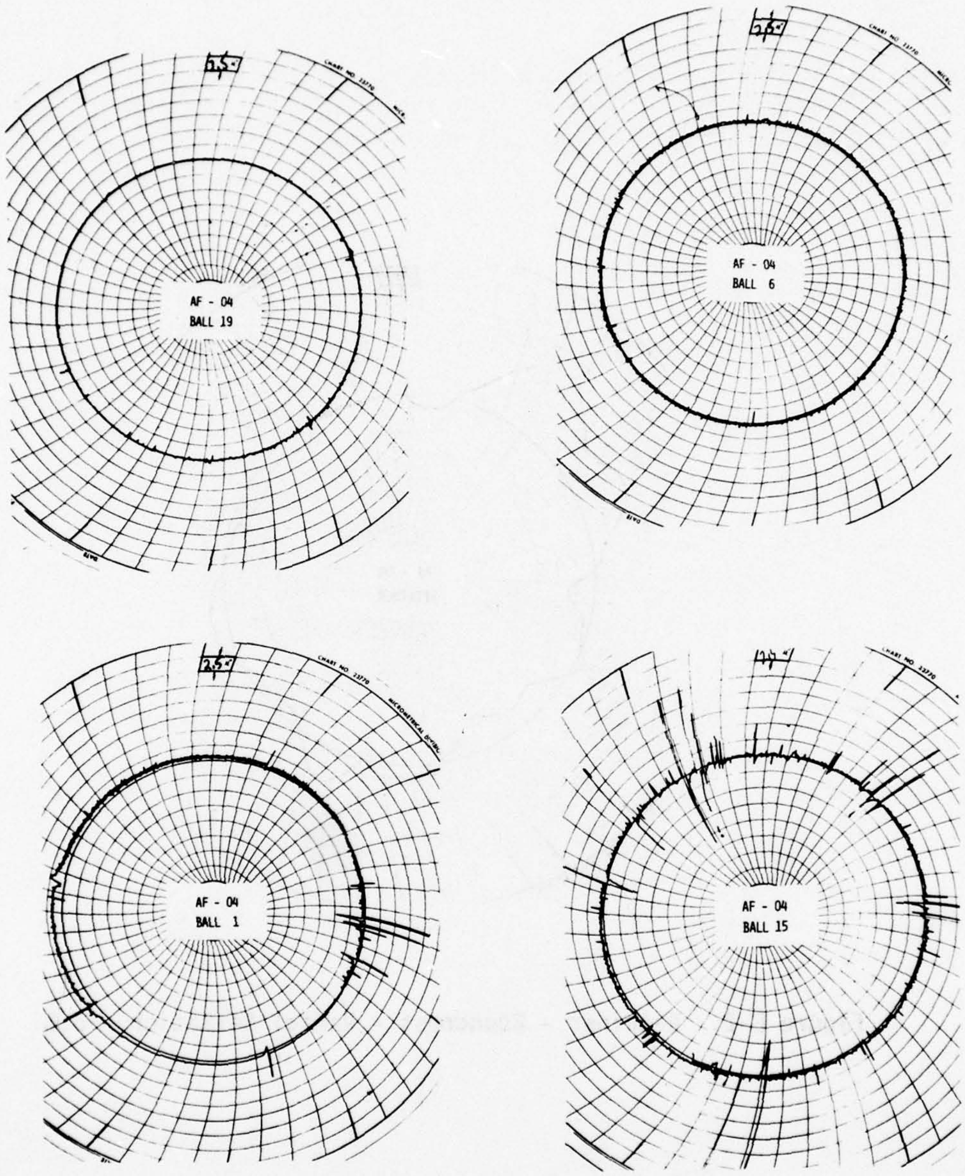


Figure E-3. Balls 19, 6, 1, 15 - Roundness

APPENDIX F

Bearing Cleaning and Lubricating Procedures.

CLEANING PROCEDURES

I. GENERAL

1. All tools and work surfaces are to be solvent cleaned with freon before use.

2. Lint proof gloves (nylon or latex) and tongs or tweezers are to be used to handle all finished bearing surfaces and all retainers and reservoirs.

3. All glassware is to be ultrasonically cleaned in n-hexane, n-heptane, or in freon and dried in an oven at 100°C before use.

4. Final rinses of bearing parts and glassware should be accomplished using the Gelman pressure rinser equipped with either a Millipore HA 0.45 micron or a Metricel GA-6 0.45 micrometer final filter.

5. Use of solvent cleaned and dried petri dishes or covered crystallizing dishes for temporary storage between operations or for transfer from place to place.

6. When using sintered nylon materials, use only freon or benzene as cleaning solvents.

7. Always use dry N_2 to bring a chamber from vacuum to atmospheric pressure.

8. Reclaim all solvents using the Buchi rotary evaporator. Analyze the residue as necessary.

Lubricants

1. Prior to using, obtain appropriate analytical data.

2. Filter using Millipore RA 1.2 micron filter.

3. Deaerate (degas) the lubricant before use.

4. After use, obtain appropriate analytical data.

Solvents

1. Filter prior to use using Millipore HA 0.45 micron filter.

2. Get appropriate analyses of all solvents before and after use (if appropriate).

Processing Record

1. Record the bearing/retainer description and all weights on the PROCESSING RECORD SHEET.

II. POROUS RETAINERS (AND RESERVOIRS)

1. Remove the retainer from the crystallizing dish, check the number scribed on it with the number on the crystallizing dish to be sure they agree.

2. Blow off loose particles with dry, filtered, oil-free N_2.

3. Visually inspect the retainer at 10x to 20x (or 20x to 30x) for defects. Record the results and photograph the retainer if appropriate.

4. Weigh the retainer to the nearest 0.1 mg.

5. Rinse the retainer with reagent grade n-hexane or n-heptane using the Gelman pressure rinser equipped with a 0.45 micron final filter.

6. Ultrasonically clean the retainer with filtered reagent grade freon for 15 minutes.

7. Remove the retainer from the ultrasonic cleaner, place it in the vacuum oven and vacuum bake at 65 ± 5°C for 24 hours.

8. Remove the retainer from the vacuum oven and weigh it to the nearest 0.1 mg.

9. Ultrasonically clean the retainer with filtered ethanol for 15 minutes.

10. Remove the retainer from the ultrasonic cleaner, place it in the vacuum oven and vacuum bake to 65 ± 5°C for 24 hours.

11. Remove the retainer from the vacuum oven and weigh it to the nearest 0.1 mg.

12. Place the retainer in the soxhlet extractor (DO NOT USE A THIMBLE) and extract it using 8000 ml of filtered n-hexane or n-heptane for a minimum of 48 hours using a relatively rapid cycle (about 30-35 minutes).

13. Remove the retainer from the soxhlet extractor and weigh it immediately to the nearest 0.1 mg.

14. Place the retainer in the vacuum oven and vacuum bake at 65° ± 5°C for 24 hours.

15. Remove the retainer from the vacuum oven and weigh it to the nearest 0.1 mg.

16. Vacuum impregnate the retainer with filtered reagent grade n-hexane or n-heptane using the vacuum desiccator impregnation chamber.

17. Remove the retainer, place it in the vacuum oven and vacuum bake at 65° ± 5°C for 24 hours.

18. Remove the retainer from the vacuum oven and weigh it to the nearest 0.1 mg.

19-24. Repeat steps 16-18 twice for a total of three cycles.

25. If the retainer is to be lubricant impregnated immediately, place the retainer on the wire holders within the bell jar on the vacuum impregnation rig and follow the instructions for lubricant impregnation of porous retainers.

26. If the clean, dry retainer is to be stored for a short period of time, place it in a clean petri dish and return it to the vacuum oven, and store under vacuum at 65° ± 5°C until used.

27. If the clean, dry retainer is to be stored indefinitely, place it in a clean, labeled petri dish and place the petri dish in a desiccator.

III. METAL COMPONENTS

1. Remove the metallic parts (races and balls) from the crystallizing dish and check the numbers scribed on the parts with the numbers on the dish to be sure they agree.

2. Visually inspect the parts at 10x to 20x (or 20x to 30x) for defects and record the results. Photograph the parts if appropriate.

3. Rinse the metallic parts using filtered reagent grade n-hexane or n-heptane using the Gelman pressure rinser equipped with a 0.45 micron final filter.

4. Ultrasonically clean the metallic parts in filtered reagent grade freon for 15 minutes.

5. Remove the metallic parts from the ultrasonic cleaner and store in a clean crystallizing dish and place it in the vacuum oven at 65° ± 5°C while the freon is removed from the ultrasonic cleaner and replaced with filtered, reagent grade ethanol (100% if possible; otherwise, 95%).

6. Remove the metallic parts from the vacuum oven and ultrasonically clean them with ethanol for 15 minutes.

7. Remove the metallic parts from the ultrasonic cleaner and place them in a clean crystallizing dish and place the dish in the vacuum oven at 65° ± 5°C for not less than one hour.

8. Remove the metallic parts from the vacuum oven and immerse them in a standard chromerge solution (25 cc Chromerge in nine pounds of H_2SO_4) for five minutes at room temperature. (440C PARTS ONLY).

9. Remove the metallic parts and rinse them thoroughly with distilled water to remove all the acid solution.

10. After rinsing, ultrasonically clean the metal parts with ethanol for 15 minutes.

11. Remove the metallic parts from the ultrasonic cleaner, place them in a clean crystallizing dish, and place the dish in the vacuum oven at 65° ± 5°C while the ethanol is removed from the ultrasonic cleaner and replaced with filtered, reagent grade freon.

12. Remove the metallic parts from the vacuum oven and ultrasonically clean them in filtered, reagent grade freon for 15 minutes.

13. Remove the metallic parts from the ultrasonic cleaner, place them in a crystallizing dish and place the dish in the vacuum oven at 65° ± 5°C for not less than one hour.

14. Allow the temperature in the oven to reach ambient room temperature, remove the metallic parts and weigh each race and the balls (as a group) individually and collectively to the nearest 0.1 mg.

15. If the metallic parts are to be stored for a short period of time, place them in a labeled crystallizing dish and place the dish in the vacuum oven at 65° ± 5°C.

16. If the metal parts are to be stored indefinitely, place them in a clean crystallizing dish, cover, and place it in a desiccator.

LUBRICATION PROCEDURES

I. POROUS RETAINERS/RESERVOIRS/ASSEMBLED BEARINGS WITHOUT ADAPTORS

1. Ultrasonically clean a glass impregnation dish and place it in the aluminum heating mold under the bell jar on the lubrication rig.

2. Remove the item from the crystallizing dish and check the number(s) scribed on it with the number(s) on the crystallizing dish to be sure they agree and visually inspect it for damage. Photograph if necessary.

3. If the item was stored in a desiccator, vacuum dry at 65° ± 5°C for 24 hours in a vacuum oven.

4. Weigh the item to the nearest 0.1 mg.

5. Filter approximately 500 ml of lubricant using a Millipore 1.2 micron filter and pour the filtered lubricant into an impregnation dish to a depth 1.5 times the width of the item.

6. Remove not less than a 15 ml sample of the lubricant for analysis.

7. Place the item on the wire holder and suspend it over the lubricant in the impregnation dish.

8. Close the impregnation chamber (by positioning the bell jar flat against the metal surface plate) and SLOWLY AND CAREFULLY deaerate (degas) the lubricant at conditions not to exceed 65° ± 5°C and 10^{-5} Torr.

9. After the deaeration is completed, lower the item into the lubricant and allow it to remain there for 24 hours at approximately 65° ± 5°C and 10^{-5} Torr.

10. Bring the chamber to atmospheric pressure using dry N_2 and allow the item to soak at 65° ± 5°C and atmospheric pressure for not less than 24 hours.

11. Recycle the pressure from atmospheric to 10^{-5} Torr and allow the item to soak at 65° ± 5°C and 10^{-5} Torr for 24 hours.

12. Bring the chamber to atmospheric pressure using dry N_2 and allow the item to soak at 65° ± 5°C and atmospheric pressure for not less than 24 hours.

13. Shut off the heat and allow the item to remain in the lubricant for 24 hours. The temperature should reach ambient room temperature during this period.

14. Slowly raise the item out of the lubricant and allow the excess lubricant to drain for not less than four hours.

15. Raise the bell jar, remove the item from the wire holder and remove any remaining excess lubricant by blowing with dry N_2 and wipe off the top and bottom faces with a lint free tissue. (DO NOT WIPE OFF RESERVOIRS).

16. Weigh the item to the nearest 0.1 mg.

17. Remove not less than a 15 ml sample of the oil remaining in the impregnation dish for analysis.

18. Visually inspect the item for damage, etc. Inspect at 10x to 20x if necessary and photograph if appropriate.

19. Store the lubricated item in a clean, labeled, covered petri dish or crystallizing dish in a desiccator until used.

20. Return the remaining lubricant from the impregnation dish to a clean glass bottle and label the bottle to indicate the use.

21. Calculate % absorption (reservoirs and retainers only).

$$\frac{Wgt_{16}-Wgt_4}{Wgt_4} \times 100 = \%\ \text{absorption}$$

II. METALLIC COMPONENTS

1. Ultrasonically clean a glass impregnation dish and place it in the aluminum heating mold under the bell jar on the lubrication rig.

2. Filter approximately 500 ml of lubricant using a Millipore 1.2 micron filter and pour the filtered lubricant into the impregnation dish.

3. Close the impregnation chamber and SLOWLY AND CAREFULLY deaerate the lubricant at conditions not to exceed 65° ± 5°C and 10^{-5} Torr. Maintain the maximum temperature and pressure until bubbling in the lubricant has ceased.

4. Remove the heat, and when the temperature reaches ambient room temperature, return the chamber to atmospheric pressure using dry, filtered N_2.

5. Remove the clean, <u>room temperature</u> metallic parts from the vacuum oven and check the number(s) scribed on the races with the number(s) on the crystallizing dish to be sure they agree.

6. Weigh each race and the balls (as a group) separately and collectively to the nearest 0.1 mg.

7. Raise the bell jar and remove not less than a 15 ml sample of the lubricant for analysis.

8. Using nichrome wire (or the wire holders) lower the races into the deaerated lubricant. Using stainless steel tongs, carefully place the balls into the lubricant.

AD-A061 075 AIR FORCE MATERIALS LAB WRIGHT-PATTERSON AFB OHIO F/G 13/9
THE PREPARATION OF 90 MM AND 100 MM BORE BEARINGS FOR PERFORMAN--ETC(U)
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9. Close the impregnation chamber and SLOWLY AND CAREFULLY deaerate the lubricant again at conditions not to exceed 65° ± 5°C and 10^{-5} Torr.

10. After deaeration is complete, soak the metallic components at 65° ± 5°C and 10^{-5} Torr for not less than 80 hours.

11. Remove the heat, and when the lubricant temperature reaches ambient room temperature, bring the chamber to atmospheric pressure using dry N_2.

12. Raise the bell jar and remove the impregnation dish and place it in a laminar flow bench.

13. Using the nichrome wire and stainless steel tongs, carefully remove the metallic components and allow them to drain on a lint free tissue. COVER THE PARTS WITH A CRYSTALLIZING DISH.

14. Remove not less than a 15 ml sample of the lubricant for analysis.

15. After draining for not less than four hours, visually inspect the metallic components and, if necessary, inspect at 10x to 20x and photograph if appropriate.

16. Weigh each race and the balls separately and collectively to the nearest 0.1 mg.

PROCESSING RECORD SHEET

Date: ____________
Name: ____________

I. IDENTIFICATION

Metallic Components

AFML Number: IR ____________ OR ____________
Manufacturer: ____________
Manufacturer P/N: ____________
Series: ____________
Manufacturer S/N: ____________
ABEC Grade: ____________
Bore (mm): ____________
Surface RMS (micro inches): ____________
O. D. (mm): ____________
Width (mm): ____________
Contact Angle: ____________
Number of Balls: ____________
Ball Diameter (in.): ____________
Race Material: ____________
Batch Number: ____________
Ball Material: ____________
Batch Number: ____________
Relieved Outer Race (Yes/No): ____________
Relieved Inner Race (Yes/No): ____________

Retainer

AFML Number: ____________
Size (Bearing Bore): ____________
Material: ____________
Grade: ____________
Porosity (%): ____________
Guide (Inner/Outer Land; Ball): ____________
Number of Pockets: ____________
ID (mm): ____________
OD (mm): ____________
Width (mm): ____________

Reservoir

AFML Number: ____________
Material: ____________

Date: ____________
Name: ____________

II. DISASSEMBLY

AFML Number:	____	Photograph Number:	____
Damaged (Yes/No):	____		____
Outer Race Number:	____		____
Inner Race Number:	____		____
Retainer Number:	____		____
Number of Balls:	____		____
Weights (gram):			
Assembled:	____		____
Outer Race:	____		____
Inner Race:	____		____
____ Balls:	____		____
Retainer:	____		____

Date: ____________
Name: ____________

III. CLEANING

A. Porous Retainers/ Reservoirs (circle correct one)

AFML Number:	____	Photograph Numbers:	____
Damaged (Yes/No):	____		____
Weights (grams):			
Step 4:	____		____
Step 8:	____		____
Step 11:	____		____
Step 13:	____		____
Step 15:	____		____
Step 18:	____		____
Step 21:	____		____
Step 24:	____		____

B. Metallic Components

AFML Number:	____	Photograph Number:	____
Damaged (Yes/No):	____		____
Weights (grams):			
Outer Race:	____		____
Inner Race:	____		____
____ Balls:	____		____
All Metal Parts:	____		____

Date: ____________
Name: ____________

IV. LUBRICATION

A. Porous Retainer/Reservoirs/Assembled Bearing without Adapters. (circle correct one).

AFML Number: ________ Photograph Number: ________
Damaged (Yes/No): ________ ________
Weights (grams): ________
- Step 4: ________ ________
- Step 16: ________ ________

Final Inspection: Photograph Number: ________
- Damaged (Yes/No): ________ ________
- Dowetting (Yes/No): ________ ________
- % Absorption: ________ ________

B. Metallic Components

AFML Number: ________ Photograph Number: ________
Damaged (Yes/No): ________ ________
Weights (grams) Step 6: ________
- Outer Race: ________ ________
- Inner Race: ________ ________
- ____ Balls: ________ ________
- All Metal Parts: ________ ________

Final Inspection: Photograph Number: ________
- Damaged (Yes/No): ________ ________
- Dewetting (Yes/No): ________ ________
- Weights (grams) Step 16: ________
  - Outer Race: ________ ________
  - Inner Race: ________ ________
  - ____ Balls: ________ ________
  - All Metal Parts: ________ ________

Date: ____________
Name: ____________

V. ASSEMBLY

AFML Number: ________ Photograph Number: ________
Damaged (Yes/No): ________ ________
Outer Race Number: ________ ________
Inner Race Number: ________ ________
Number of Balls: ________ ________
Weights (grams): ________
- Outer Race: ________ ________
- Inner Race: ________ ________
- ____ Balls: ________ ________
- Retainer: ________ ________
- Assembled: ________ ________

VI. NOTES

REFERENCES

1. R. J. Benzing and J. R. Strang, Failure Mode Analysis of Lubricated Satellite Components, AFML-TR-73-188, May 1974.

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